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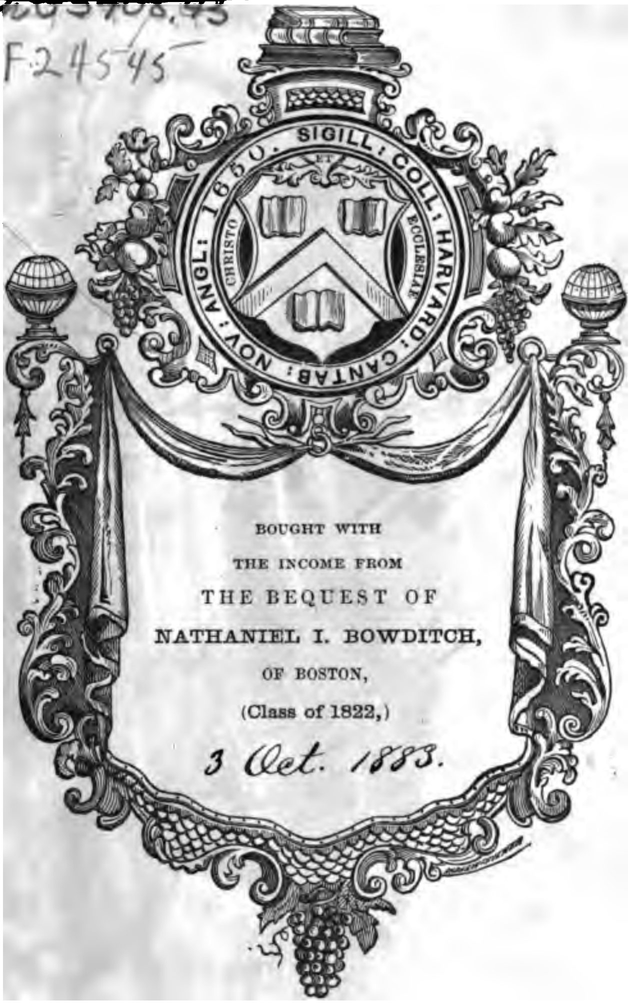
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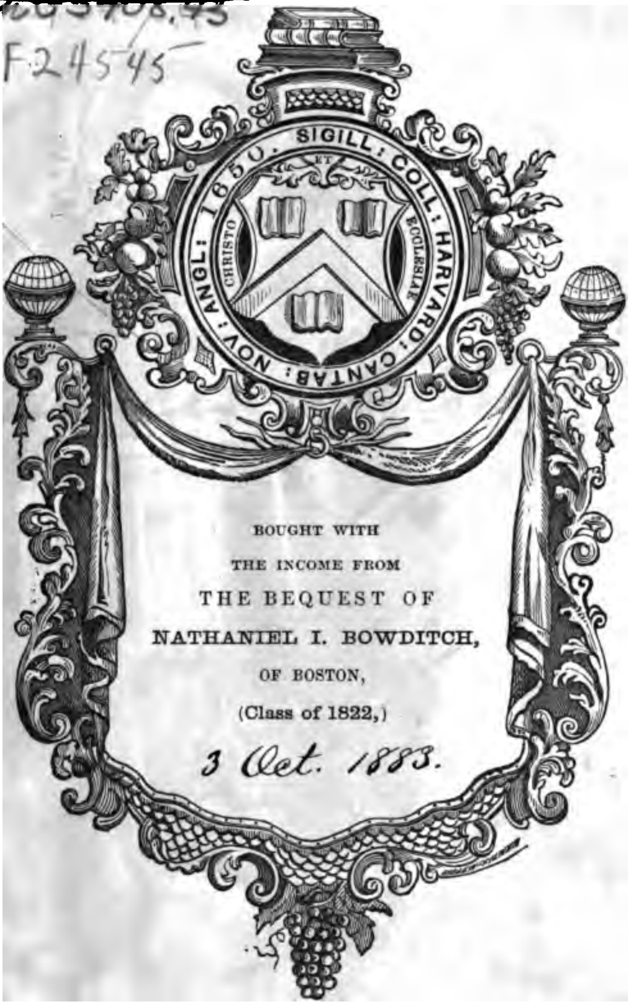
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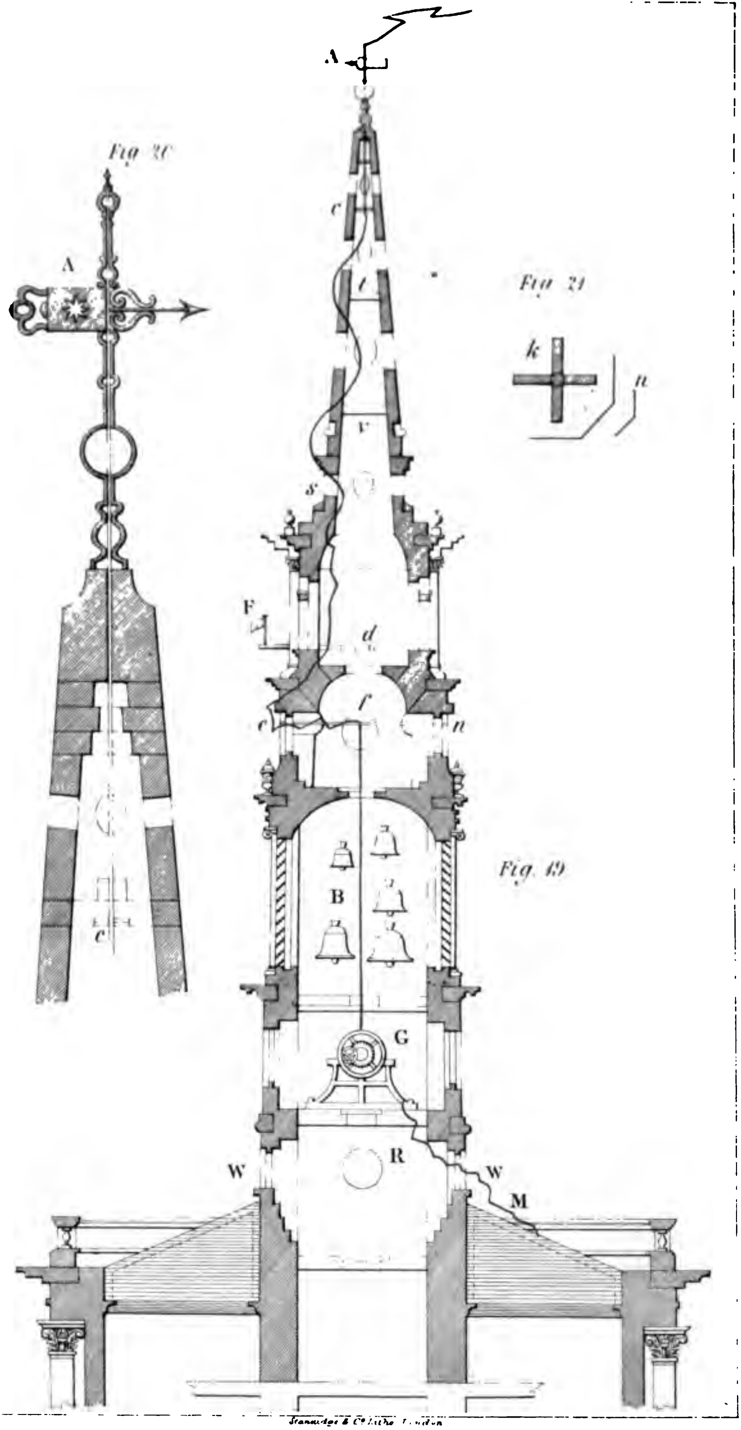

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STEEPLE OF THE CHURCH OF ST MARTIN IN THE FIELDS LONDON

[illegible] W. PARKER, [illegible]

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Plate 1

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STEEPLE OF THE CHURCH OF ST MARTIN IN THE FIELDS LONDON

ON THE NATURE

OF

THUNDERSTORMS;

AND ON THE MEANS OF

PROTECTING BUILDINGS AND SHIPPING

AGAINST THE

DESTRUCTIVE EFFECTS OF LIGHTNING.

Sir William
BY W. SNOW HARRIS, F.R.S.

LONDON:
JOHN W. PARKER, WEST STRAND.
M.DCCC.XLIII.

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TO

THE RIGHT HONOURABLE

SIR GEORGE COCKBURN, G.C.B., F.R.S.,

ADMIRAL OF THE RED, MAJOR-GENERAL OF THE ROYAL
MARINES, ONE OF THE LORDS COMMISSIONERS
OF THE ADMIRALTY,
&c., &c., &c.

Dear Sir,

Having been honoured by your permission to dedicate to you the following pages, I avail myself of the opportunity to express publicly my sense of the full consideration which, so long since as the year 1830, you gave to my proposals for defending Her Majesty's ships from the destructive effects of Lightning.

Your anxious regard for the national welfare, and especially for the interests of the Navy of England, would necessarily have ensured a patient investigation of such proposals; but the kind attention with which you received my statements, and the candour and fairness with which you inquired into the many objections that were urged against them, have rendered the distinction of your approbation most valuable to me.

That your opinion of the propriety of giving my method of fixing conductors in ships an adequate trial was not erroneous, is fully shown by the uniform success which has attended its adoption in about thirty vessels of Her Majesty's Navy, which during the last twelve years have been exposed to heavy storms of lightning in various latitudes, without experiencing the slightest inconvenience or damage.

Permit me, Sir, to add the expression of my respect for the many eminent public services which you have rendered this great maritime nation, and my grateful acknowledgment of the many personal kindnesses I have received at your hands. That your valuable life may long be spared to your country and to your friends, is the earnest wish of,

Dear Sir,

Your faithful friend and servant,

Snow Harris.

PREFACE.

The fact of electrical conduction by metallic substances having been so long and so well established, any further discussion of the application of this principle to the purpose of protection against lightning may possibly appear to persons, conversant with such subjects, as in some degree superfluous. The damage, however, which so frequently occurs in thunderstorms, attended as it is with loss of life, and with serious inconvenience to the best interests of the country, may be fairly adduced as a sufficient reply to such an opinion.

The beautiful spire of St. Martin's church, in London, has been recently rebuilt, at a cost of full one thousand pounds sterling, in consequence of an explosion of lightning, which fell on it in July last. Brixton church, near London, had also to undergo extensive repairs, rendered necessary from the same cause. In January, 1841, the spires of Spitalfields and Streatham churches, were struck by lightning, and the latter nearly destroyed:

and in August of the same year an electrical discharge shook the spires of St. Martin's and St. Michael's churches, at Liverpool, both modern edifices of a costly and elaborate construction. In January, 1836, the spire of St. Michael's church, near Cork, was rent by lightning down to its very base; and in the following October the magnificent spire of Christ church, Doncaster, was almost totally destroyed by a similar discharge.

Thus, in the United Kingdom alone, and within the short space of five years, we find at least eight churches to have been either severely damaged or partially demolished by lightning; to this list of casualties may be added the fine old church of Exton, in Rutland, which, according to the public journals, was in great measure destroyed in a thunderstorm, so lately as the 25th of last April. A writer in NICHOLSON's *Journal of Science*, states that he has made a calculation of the average annual amount of damage done by lightning in England alone, and that it cannot be far short of fifty thousand pounds.

In the British Navy the effects of lightning have been most disastrous. Since the commencement of the war in 1793, more than two hundred and fifty ships are known to have suffered in thunderstorms. It is not possible to state with any degree of precision the total amount of damage done, as all the instances in which ships have suffered cannot be well ascertained: some idea, however, may be formed of it from the following facts, derived from the official journals of Her Majesty's ships, deposited at the Admiralty. In one hundred and fifty cases, the majority of which occurred between the years 1799 and 1815, nearly one hundred lower masts of line-of-battle ships and frigates, with a corresponding number of topmasts and smaller spars, together with various stores, were wholly or partially destroyed. One ship in eight was set on fire in some part of the rigging or sails; upwards of seventy seamen were killed, and one hundred and thirty-three wounded, exclusive of nineteen cases in which the number of wounded is returned as "many" or "several." In one-tenth of these cases the ships were completely disabled, and they were compelled in many instances to leave their stations, and that too at a critical period of our history. The expenditure in these few cases in the mere material, could not have been far short of one hundred thousand pounds sterling. So that if the whole amount of the loss to the public, in men, in money, and in services of ships, could be ascertained, it would necessarily prove to be enormous; more especially when we take into account the expense of the detention and refit of the damaged vessels, the average cost of a single line-of-battle ship to the country being one hundred pounds per diem and upwards. Now between the years 1809 and 1815, that is to say, within the short period of six years, full thirty sail of the line, and fifteen frigates, were more or less disabled.

A very considerable portion of this mass of destruction occurred, it is true, at a time when a great number of ships were required; but at a more recent period, in time of peace, when the Navy has been greatly reduced, we find a large amount of these casualties to be constantly occurring. On the Mediterranean station alone, between the years 1838 and 1840, the *Rodney*, *Powerful*, *Ceylon*, *Tribune*, *Scorpion*, *Wasp*, *Tyne*, and *Blazer*, were struck by lightning, and many of them severely damaged: the *Rodney*, in addition to the destruction of her mainmast, was set on fire. In little more than twelve months, about the year 1830, three line-of-battle ships, a frigate, and a brig, were also more or less disabled. In other parts of the world we have lately had the *Rhadamanthus*, *Gorgon*, *Snake*, *Racehorse*, *Pique*, and many others, damaged by lightning; and in 1832, the *Southampton*, of fifty guns, narrowly escaped being blown up in the Downs.

It has been suggested that many ships reported as "missing," have been destroyed in thunderstorms, a surmise almost converted into a reality, by the ravages which lightning is known to be capable of producing. From a reference to the official log of the *Lacedæmonian*, and to the evidence of Admiral Jackson, who then commanded her, it appears, that His Majesty's ship *Peacock* disappeared during a violent storm of lightning on the coast of Georgia, in the year 1814. The *Loup Cervier*, another of His Majesty's ships, was last seen off Charlestown, on the evening of a severe thunderstorm, and has not since been heard of. When His Majesty's ship *Resistance*, of forty-four guns, was blown up by lightning in the Straits of Malacca, in the year 1798, two or three of the crew were picked up by a Malay proa, which happened to be in company; but for this circumstance, the fate of this ship would have remained in the same obscurity which now hangs over so many vessels reported as "missing," as all the rest of the crew perished.

The journals of the ships of the Honourable East India Company furnish appalling statements of the damage and loss of life, caused by the electrical explosions which have fallen on them, while freighted with the rich products of the East: even so lately as 1842, the *Coote*, of twenty guns, one of the navy of this great mercantile power, had her masts shivered in pieces by lightning at Madras.

Though we have not the same means of ascertaining the damage done to our mercantile marine, yet the loss to the shipping interest, in consequence of lightning, must be extremely great. Scarcely a year passes, without a calamitous account appearing in the public prints, of some fine merchant ship having been damaged or totally destroyed. In March last, the *Toronto*, one of the splendid packets which sail between London and New York, was struck by lightning, which killed one of the crew, and damaged the vessel; and in August, 1842, the *Defiance*, a large transport laden with Government stores, including rockets and gunpowder, had her mainmast completely rent through to the keel by an electrical discharge off Nankin; the ship was filled with a sulphurous smoke, and the greatest consternation prevailed among the troops and seamen, from the dread of an immediate explosion. In May, 1840, the ship *Madras* was set on fire, and a portion of her side was driven out by an electrical explosion, and in 1839 a similar accident befel a large barque called the *John and James* off Algiers, so that she was with difficulty prevented from sinking. In 1838, the *Orwell*, a large trader laden with cotton, was set on fire, and narrowly escaped total destruction. Within a few years the merchant ships *Tanjore*, *Poland*, *Logan*, *Ruthelia*, *Bolivar*, *Boston*, and *Lydia*, are known to have been entirely consumed.

However well, therefore, the fact of electrical conduction may be known,—however well scientific men may be agreed that, by the judicious employment of metallic bodies, we may ensure protection against lightning,—certain it is that the principle itself is far from being generally understood, or universally adopted. Indeed, to *existing* prejudices arising entirely out of a misapprehension of the laws of electrical discharge, may be traced the great destruction of life and property so frequently occurring from the effects of lightning.

It is not easy to explain how, in the present advanced state of natural knowledge, so many anomalous views and opinions on this interesting subject should pervade the public mind, since in no department of physical science is the field of observation more fertile, or the path of experience more direct and certain. We have at our command the results of observation for nearly a century, during which time lightning rods have been employed; a great many instances are to be found, in which lightning has fallen on buildings under a variety of peculiar circumstances. In some cases lightning rods have been present, in others not: moreover, we can successfully imitate by artificial means the great operations of nature, and examine experimentally every probable result of a shock of lightning, and every possible contingency attendant on it. We ought, therefore, to find no difficulty in arriving at a practical solution of such questions as these:—Is the application of a lightning conductor desirable in any particular case? May it, by a species of attractive force inherent in it, cause a discharge of lightning, which otherwise, would not have occurred in this particular direction? If so, may it occasion the damage it was set up to avert, through its inability to meet the explosion that may fall on it? Is it liable to produce destructive effects, by any species of lateral discharge of the electricity in passing along it? What are the best dimensions and form of a lightning conductor? and such like. If such questions as these cannot now be determined, they in all probability never will be.

To bring the subject, therefore, of lightning rods, and the amount of our knowledge of their practical operation, into such a form as may be readily apprehended by those whose habits of inquiry have not led them into scientific pursuits,—and to remove the misapprehension which exists as to the attractive effect of metallic bodies in storms of lightning, is the object of this treatise; and as it is most important, that no means of protection from danger which we are permitted to employ, should, through the prevalence of popular misapprehension, or want of information, be unwisely neglected, I cannot but venture to hope, that with so many important facts before us, the following pages may not be deemed altogether uncalled for, or without claims to public attention.

Snow Harris.

6, *Windsor Villas, Plymouth,*
May 1, 1843.

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SECTION I.

GENERAL VIEW OF NATURAL AND ARTIFICIAL ELECTRICITY.

Electricity considered in relation to common matter—Conditions of a Thunderstorm—Insulation—Charge—Conduction—Discharge, &c.—Identity of Natural and Artificial Electricity—Nature of ordinary Electrical arrangements producing Disruptive Discharge—Various Phenomena of Thunder and Lightning—Appearances termed Fire Balls—Sulphurous odour of the Electrical Discharge—Artificial discharges of various kinds—Luminous appearances similar to those in Nature—Further observations on Thunder Clouds—Stationary Discharges—Discharges liable to occur during the Motion of Clouds—Possible Causes of Discharge—The Returning Stroke.

NATURAL AND ARTIFICIAL ELECTRICITY.

Electricity considered in relation to Common Matter.

1. Before entering upon the subject of the application of metallic substances to buildings and ships with a view to their protection from lightning, it may not be unimportant, to review the amount of information we are in possession of, relative to the nature and operation of thunderstorms.

A large induction of facts, leaves little doubt of the existence of some elementary or primordial principle in nature, every where present, and intimately associated with the particles of common matter according to some general law. In what this element consists, we are quite ignorant; we know, however, that there is such a constituent principle, and that it is capable of exerting, under given circumstances, an all-powerful action—hence it may be considered as a species of unknown physical force, or agency, the laws of which it is our business to investigate.

2. Now it is no objection to the practical results of such an inquiry, to say that we are ignorant of the nature of the agency with which we are dealing —it being the great end of modern philosophy rather to trace, and apply the uniform relations of certain facts, than to speculate upon the nature of the mysterious causation, upon which the connection depends. Thus Newton was content to examine

the laws of gravity, and the relations of this force to common matter, without in any way meddling with its nature as an occult cause—and from this method of inquiry the happiest consequences have resulted. The same method is equally applicable to the subtle principle active in a thunderstorm: we may arrive at all the practical information we require relative to this grand, yet fearful display of its powers, even although we should never understand its nature as a primary source of causation.

3. This physical force or agency has been termed electricity*, and there is some strong evidence for supposing it to be an extremely attenuated and subtle kind of matter; differing, however, in its properties from any form of matter of which we have cognizance.

It is insensible to ordinary perception so long as it is distributed amongst the particles of bodies according to a given law. In this state it is said to be neutral, or inactive: when, however, the equilibrium of distribution is from any cause disturbed, then a variety of interesting phenomena begin to appear, and the electrical agency manifests a tendency to return to its previous state of quiescence.

4. A variety of natural and artificial operations, affect the neutral electrical state of matter. Under natural operations may be classed changes of temperature, changes in the form of bodies, chemical changes, &c.; thus brimstone, chocolate fresh from the mill,

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* The Greeks observed its effects in amber, ἤλεκτρον, hence the term.

wax, resin, &c., when melted, become electrical in cooling; the tourmalin also, and many other substances, evince electrical signs under a change of temperature. In the decomposition of water by means of sulphuric acid and zinc, we find the bottle in which the chemical action is proceeding strongly electrical; and it is a remarkable fact that, during the progress of thunderstorms, the vapour of the atmosphere is condensed into rain, or frozen into hail, and the general temperature of the air altogether changed.

Under artificial operations may be classed friction, pressure, and other mechanical actions:—the electrical machine, essentially a plate or cylinder of glass, made to revolve between or against fixed cushions, is sufficiently illustrative of this—we observe brilliantly luminous sparks fly round the glass, and dart off from a metallic substance opposed to it, in consequence of the disturbed state of the electrical distribution in these bodies.

5. Amongst the various relations of electricity to common matter, we find the following:—Some bodies facilitate the transmission of electrical action in so much greater degree than others, that they have been considered in the light of conductors of electricity: other bodies, on the contrary, admit of so little freedom in this respect, that they have been denominated non-conductors, or insulators of electricity. The distinction, however, between conductors and non-conductors, although more or less arbitrary, may still be sufficiently defined for practical purposes:—thus all the metals more particu-

larly may be taken as conducting bodies, whilst all vitreous and resinous substances may be considered as non-conducting bodies, or insulators. Hence it is, that we find the metallic conductors opposed to the cylinder of an electrical machine, supported on a glass pillar; by which the active electricity developed by the friction, becomes as it were imprisoned,—and accumulated on the metal.

6. It should however be clearly understood, that there are no substances which *perfectly* conduct or *perfectly* obstruct the transmission of electricity, their insulating or conducting power being only a difference in degree: still the differences are so great between various substances, that if classed in relation to such differences, those at the extremes of the series, admit of being considered, the one as conductors the other as insulators. Thus, while vitreous and resinous bodies admit of but extremely slow conduction, during which sensible and even considerable portions of time elapse, metallic bodies allow conduction to proceed with incredible rapidity. Professor Wheatstone, by a highly ingenious experimental process, has clearly shown, that the transmission of accumulated electricity through a copper wire, one-fifteenth of an inch in diameter, and about half a mile in length, proceeds at the rate of 576,000 miles in a second of time; supposing the electrical action to move from one extremity to the other; and that the light of the spark produced by it, has a less duration than the one-millionth part of a second.

The learned Mr. Cavendish, in the course of some extensive inquiries into the electricity of the torpedo, found the difference between the conducting powers of iron and water, to be nearly in the ratio of four hundred millions to one; that is to say, electricity meets with no more resistance in passing through an iron rod four hundred millions of inches long, than it would meet with in passing through a column of water of the same diameter, only one inch long*.

TABLE *showing the order of the Conducting and Insulating Powers of various Substances.*

	CONDUCTORS.		INSULATORS.
Most perfect.	All known metals.	Less perfect.	Ice at 0° of Fahrenheit.
	Well-burned charcoal.		Dried vegetable substance.
	Plumbago.		Dried animal substances.
	Burning gaseous matter, as flame.		Parchment. Leather. Feathers.
	Smoke.		Baked wood.
	Concentrated acids.		Oils and fatty substances.
Less perfect.	Dilute acids.		Bituminous matter.
	Saline fluids.		Silk.
	Living animals.	Most perfect.	Animal fur and hair.
	Living vegetables.		Dry gases, including the atmosphere.
	Wood in its ordinary state.		Pure steam of high elasticity.
	Snow and ice.		Glass and all vitrefactions.
Imperfect.	Aqueous vapour.		Diamond. Transparent gems.
	Common earth and stone.		Talc.
	Dry chalk and lime.		Amber.
	Marble and porcelain.		All resins and resinous bodies.
	Paper.		Brimstone.
	Alkaline matter.		Shell-lac.

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* *Phil. Trans.* for 1834, Part II.

7. If we arrange various kinds of substances in series, according to the comparative degree of resistance they offer to the transmission of electricity, we obtain the following order. The first column in the preceding Table contains the best conductors, and leads by degrees into the second column, in the order of their increasing resistance, until we arrive at the opposite extreme.

The order above given, is sufficiently near the truth: it is almost impracticable however, to assign the exact place of some of the equivocal substances, more especially as their conducting power is liable to vary from many accidental causes. We find, for example, certain specimens of common glass with so great a degree of conducting power, as to be totally unfit for the electrical purposes to which glass is usually applied. All charcoal will not conduct equally well, and some bodies which conduct badly as solids, will, by a change of temperature up to fluidity, become immediately conductors: thus ice at 0° of Fahrenheit is an insulator, but on approaching the melting point it becomes a conductor;—the conducting power of green vegetables, and raw meat, depends on the fluids they contain. The extremes of the series, however, are perfectly defined; if we commence with the metals, we have the order of conducting power, and conversely, by commencing with shell-lac, we have the order of insulating power.

For the purpose of a greater degree of generalization, we may include, in the conducting class, all metals and metallic ores, acids, saline bodies, all fluids except oils, also stones and earthy matter, living animals and vegetables.

Under the insulating class, we may comprise all resinous and bituminous matter, all vitreous matter, all gaseous matter, precious stones, dry animal and vegetable matter, silk and oils.

8. The following is an easy and simple experimental illustration of the conducting and insulating power of various bodies in respect of ordinary electricity.

Let a succession of sparks about two inches in length, continue to pass from the insulated conductor of an electrical machine to a metallic ball in connection with the ground. Apply now a stick of sealing-wax, or a dry rod of glass, to the conductor, no sensible effect will be produced on the current of sparks. But if the conductor be touched with a rod of wood, or put into communication with the walls of the building, the sparks will immediately cease, evidently showing that the accumulated electricity had been by these last substances carried off, whilst the wax and glass evinced no such power. In this way we may test the conducting power of the various substances above given, either directly, or by inclosing them in non-conducting tubes.

9. Although the distinction between conductors and non-conductors of electricity is to a great extent arbitrary, yet it is plain from the above facts, that such a distinction, in a positive sense, is quite admissible. Thus the substances com-

mencing the first column of the preceding table, may be taken as being more especially conductors; those terminating the second, as obstructors or non-conductors of electricity: and the great practical fact which marks the distinction between them is this,—that the substances considered more especially as insulators, oppose such complete resistance to the transmission of electrical action, that an instantaneous return of the disturbance to a state of quiescence (3), is *never* effected through them, without mechanical violence and displacement of their particles, without a vivid evolution of light and heat, and without producing at the same time, all the furious effects peculiar to an irresistible expansive force. The best conducting substances, on the contrary, yielding as they do almost immediately to the electrical transmission (6), at once quiet the disturbance without any such disastrous consequences. The transmission through these is comparatively passive; and it is only in some few instances to be hereafter considered, that we find the small degree of resisting power they possess, productive of any ill consequence, and *then* only to the conducting substance itself, not to neighbouring bodies.

Electrical conditions of a Thunderstorm.

10. We are indebted to Dr. Faraday's valuable and most interesting series of Inquiries in Electricity*, for very practical and sound views of the

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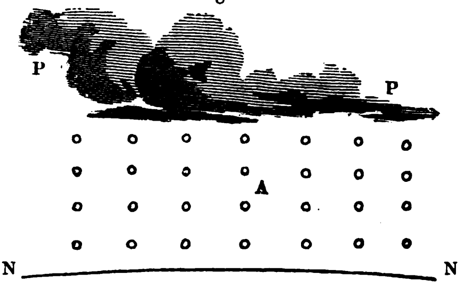
* *Phil. Trans.* 1831, to 1838.

nature of electrical action. These we shall now proceed to apply to the conditions of a thunderstorm, which will serve at the same time to explain them.

A thunderstorm may be considered, as the result of a great electrical disturbance (3) (4), between masses of vapour condensed in the atmosphere under the form of clouds, a portion of the earth's surface directly opposed to these masses, and the intermediate air; the particles of which, instead of allowing the disturbance to subside rapidly, virtually maintain it up to a point, at which its force is no longer to be resisted. For example; let the mass of vapour P P (fig. 1,) under the form of cloud, be supposed to contain active electricity, in consequence of some of those changes in the condition of the atmosphere, to which we have already alluded (4). Let N N be a portion of the earth's surface directly opposed to these masses; and A the intermediate atmospheric particles. Now, Faraday has shown, that in such a case as this, all these intermediate particles assume a peculiar forced

Fig. 1.



electrical state, which he terms a polarized state. By way of typical illustration, let *a*, *b*, *c* (fig. 2), represent three of these consecutive particles, and suppose in their neutral condition the electrical distribution of each particle to be uniform and equal, as indicated by the equalization of the dark and light squares. Now, when these particles become placed under the influence of a thunderstorm, as represented in figs. 1 and 4, there would be no longer this uniform distribution. The electricity of the particles would be compelled to assume some new condition, such, for example, as that shown in fig. 3; that is, we may consider the electrical agency as being no longer distributed according to a law of quiescence, but to be, as it were, collected in the particle in some other way, according to a law of disturbance. Suppose this represented by the shadowed and light portions of the particles *a′ b′ c′* (fig. 3), the dense portions being constrained to appear in opposition to the light ones; and let us further imagine, that this state consists in a concen-

Fig. 2.

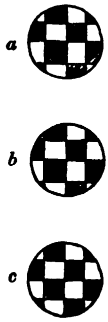
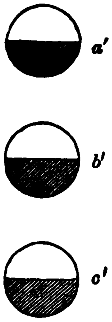


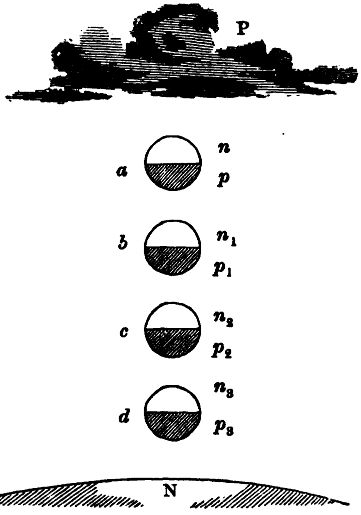
Fig. 3.



tration of the electricity of each particle in one of its opposite faces: in this case the particles are said to be polarized.

11. The immediate consequence of such a forced state as this, is, that the electricity, rendered active by any of the causes above-mentioned (4), propagates through an insulating medium, such as the air, a species of disturbance from particle to particle, which at last arriving at distant conducting substances, elicits an active electrical condition of such substances, similar in effect to the primary disturbance, but opposite in kind. This Faraday shows to be the essence of that peculiar action of electrified on distant bodies, termed induction. Thus, assuming by way of illustration that P (fig. 4)

Fig. 4.



were a cloud containing a greater quantity of electricity, than it could support in a state of quiescence, there would be immediately propagated through the intermediate particles of air *a*, *b*, *c*, *d*, &c., an induced action of this kind,—the intermediate particles *a*, *b*, *c*, *d*, would be constrained to assume the polarized state just mentioned. There would be, according to the principle we have just supposed, an alternate electrical condensation and exhaustion P *n*, pn_1, p_1n_2, &c., brought into play, which at last reaching the earth's surface, would there elicit an electrical force, N, exactly equal to the force at P, but of an opposite or neutralizing quality; so that there would arise at N, by this kind of action, an electrical exhaustion or displacement, just sufficient to tranquillize the active accumulation at P. Now it is of no consequence to the general result, which of these opposite states P, N be supposed to reside in the cloud P: we evidently may conceive the whole chain (fig. 4) to exist without any actual change in its condition, although the point N were imagined to be the state of the cloud, and P that of the earth: the intermediate particles *a*, *b*, *c*, *d*, would still become polarized in the same way, but in an opposite sense. We have only to conceive the figure reversed, and this will be immediately apparent, the conducting surfaces of the clouds and earth, being nothing more than the terminating planes of a great intermediate action, set up between them in a given direction*.

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* Faraday has not unaptly termed insulating bodies dielectrics, and the media, through which induction is sustained, dielectric media, as expressive of substances through which electrical action is propagated from particle to particle.

12. The induced disturbance at N, in the points immediately opposed to the electrical cloud P, may be considered as a species of reaction, and as giving origin to a new force. We have therefore, in every disturbance of this kind, two forces present, exactly equal and opposite to each other. These opposite electrical states, have been imagined by some philosophers, to depend on the presence of two equally powerful, but dissimilar agents, termed the vitreous and resinous electricities, from the circumstance of one of them being very commonly produced by the excitation of vitreous, the other by the excitation of resinous substances. There is not, however, any essential difference between them, so far as relates to their action as physical forces; and although, for the sake of perspicuity, they may be considered as positive and negative powers, or as positive and negative electricities; yet it is still to be remembered, that one is as much a positive force as the other. It will be immediately perceived, that the two forces must necessarily exist both at the same time (11) as at P, N (fig. 4): hence it is found impossible to charge common matter with one of them, without the other appearing somewhere, either in near or distant bodies*, just as it is impossible to pull against a fixed point, without eliciting in that point, an equal and opposite force.

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* FARADAY'S *Researches in Electricity*, p. 365.

Insulation—Conduction—Charge—Discharge, &c.

13. These points being apprehended, we are immediately prepared to receive the simple and lucid explanation, which this eminent philosopher has given us, of the terms, insulation, conduction, charge, discharge, &c.

We have already shown (11) in what that peculiar and wonderful influence, termed electrical induction, may be said to consist, viz., a polarization, or forced state of material particles, by which an action is propagated, and made to appear in bodies however distant. This we have conventionally, or typically, represented in fig. 4., page 13; now supposing this state of the particles could be maintained under all circumstances, complete obstruction to the return of the opposite forces to a state of quiescence would be the result; and we should arrive at perfect insulation of these forces. This however is not the case, the constrained state of the particles *will not* remain, except for a limited portion of time. Thus, in fig. 4, the positive force in P, will, if sufficient time be allowed, discharge into the negative force *n* of particle *a*, the positive force of this particle into the negative force n_1 of particle *b*, and so on to the negative force N, until the whole disturbance is quieted, and the polarization of the particles *a, b, c, d*, reduced. This process constitutes conduction, and it always proceeds more or less rapidly through every kind of substance; the more rapidly however it can proceed, the better the conducting power, and conversely, the less freely it can proceed, the more perfect the insulating power (5).

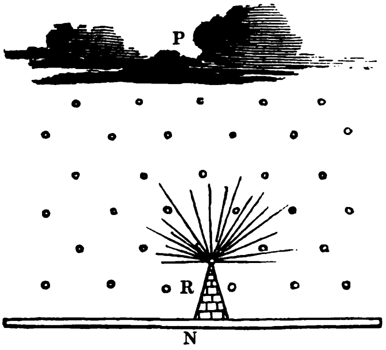
Insulating bodies are therefore, as already observed (6), only conductors of a rigid and stubborn kind, the particles of which return to their normal state so slowly, that for a limited portion of time, they admit of being considered as exceptions to the general law of conduction; yet it is upon these bodies that the process of induction depends, and upon this process depends further, the state of things called electrical charge, typically illustrated in fig. 4. As long as the particles *a*, *b*, *c*, &c., can suffer the constrained state in which they are placed (10), so long will the charge be maintained with but small loss; but when they can no longer resist the tendency of the opposite electrical forces P, N, to combine throughout the series, we have immediately what Faraday terms disruptive discharge—that is to say, the particles in fig. 1 (page 11), are displaced and broken through, with a greater or less degree of mechanical violence. In this case, the electrical disturbance in the particles having become as great as they can sustain, any tendency to further disturbance, instead of inducing further change, subverts the whole system, and a violent reunion of the opposite electrical forces instantly ensues.

14. Although such discharges are of a sudden and violent character, and productive of damage to bodies through which they pass, yet they occasion-

ally become so modified by various circumstances, as to assume a more progressive and quiet form, often free from any attendant danger whatever.

If a pointed metallic rod, R, (fig. 5,) project freely into a charged system, P, R, N, from one of its terminating planes N, the polarized particles immediately at the extremity of the rod have the forced condition (10) so highly exalted, that it terminates in discharge upon the next or more remote particles, the electrical condition of which is less intense. The consequence of this is, a luminous brush of beautifully coloured light, attended by a sort of roaring noise. This brush discharge may be considered as taking place between a good and bad conductor: it is, in fact, an intermitting series of electrical sparks between metal and air; but in such rapid succession as to convey the idea of a continuous stream. The discharge in this case always commences at the root of the brush, and is complete at the point of the rod, before the more distant particles attain the same intensity: hence the discharge is progressive, and occupies a sensible time.

Fig. 5.



Brush discharge, by means of pointed or angular bodies, will, under certain conditions of conduction, assume the appearance of a luminous star, especially when it is proceeding from a negative or resinous electricity (12). Hence the observation, that electrical discharge, *from* a pointed conductor, is attended by a luminous brush of rays, but *toward* a pointed conductor by a star of light.

When the air in contact with a metallic rod is becoming rapidly charged, we have another species of discharge, termed glow discharge; that is to say, the metal in contact with the electrified particles becomes covered with a glow of lambent light, producing a beautiful effect.

15. Dr. Watson, in the 48th vol. of the *Phil. Trans.*, has collected out of ancient history several interesting notices of these electrical appearances. Thus Pliny, in his *Natural History*, tells us "that stars settled on the sail-yards and masts of ships with an audible sound: also on the spears of soldiers." Seneca, again, in his *Natural Questions* says, that the "spears seemed to be on fire in the Roman camp." Similar appearances are mentioned by Cæsar and Livy.

In more recent periods, we find repeated notices of similar natural phenomena. They are called by the French and Spaniards, St. Helmo's, or St. Elmo's fires; by the Italians, the fires of St. Peter and St. Nicholas. On ship-board in this country, sailors call them comazants. "In the night (says the Count de Forbin) we saw on different parts of the ship above thirty St. Helmo's fires; one of them was more than a foot and half in height; its noise resembled that of fired gunpowder*."

Captain Waddel, of the merchant ship *Dover*, met with a heavy electrical storm in January, 1748: he says, "Sundry very large comazants (as we call them) settled on the spindles, and burnt like very large torches†." The ship was soon after struck by lightning. Captain Fanshawe, R.N., observed on board His Majesty's ship *Newcastle*, in May, 1821, luminous appearances "resembling the flame of a gas light" on the extremities of the masts; the lights were visible "sometimes on one mast, sometimes on another, and sometimes on all of them." The ship was sailing from Bermuda to Halifax, the weather unsettled and squally, with a "mass of black clouds close astern," vivid lightning and thunder occasionally.

At Plauzet, in France, the three pointed extremities of the cross of the steeple, always appeared surrounded with a body of flame during great storms of lightning‡.

M. Toscan, the librarian of natural history in the Botanic Gardens in Paris, witnessed, in May, 1803, during the presence of heavy black clouds, a vivid glow of electrical light on a bent iron bar surrounding a wall in the gardens: it gave him the idea of a large ball of fire of a foot in diameter, and lasted eighteen seconds. This glow discharge preceded a heavy stroke of lightning on the house about six feet distant*.

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* *Phil. Trans.* vol. xlviii.

† *Phil. Trans.*, vol. xlvi., p. 3.

‡ PRIESTLEY'S *History of Electricity*, p. 373.

16. The fact of discharge occurring between bad and good conductors, in such way as to produce a spark, leads in some degree to an explanation of certain electrical explosions observed to occur, although rarely, in an apparently serene sky. Thus His Majesty's ship *Dictator* is said to have been struck and damaged by a fire-ball at Martinique, in the year 1794, during fine weather. In this case the surface of the sea may have discharged upon the nearest particles of air, which, by some of those changes so frequently taking place in the atmosphere, had become polarized. It is not improbable, that on the same principle, luminous electrical discharges may occur between particles of polarized air in different states of intensity, producing those progressive appearances more especially called meteors. These have all the characters of a dense electrical discharge, propagated, as it were, from particle to particle through a considerable space; and probably dragging into its path, light vapours and inflammable matter floating in the atmosphere, and increasing by their intense ignition the luminous and highly brilliant appearance which such meteors exhibit.

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* GILB. *Annal.*, xiii., p. 484.

Identity of common Electricity with the agency of Lightning.

17. The years 1745 and 1746 mark an important era in the history of physical science. Von Kleist, dean of the cathedral of Camin, and some Dutch philosophers in the university of Leyden, in endeavouring to confine electricity within the limits of a small phial, discovered a method of accumulating it on glass to a most unprecedented degree, and of subsequently discharging it through bodies, in such a way as to produce the most powerful and astonishing effects. By these discharges, a fearful sensation could be impressed on living animals—even life itself destroyed;—metallic substances could be violently heated, fused, and ignited;—inflammable bodies set on fire, and the most compact substances scattered in pieces, as if acted on by a violent expansive force. When, therefore, the cause of lightning became identified with that of ordinary electricity, with the very element, as it were, by which such effects were produced; and the gigantic attempt of Franklin (about seven years afterwards) actually to draw electricity from the clouds, and appropriate it in a similar way to the purpose of experiment, had fully succeeded,—then it was, that these artificial electrical accumulations and discharges acquired a more than ordinary interest, as furnishing us with a valuable means of investigating by minor experiments, the laws and operations of the great discharge in thunderstorms.

18. The identity of common electricity and lightning, although not fully verified until the year 1752, had nevertheless been long suspected. Mr. Gray, an English electrician, observes (*Phil. Trans.* for 1735), that "the electric fire seems to be of the same nature with that of thunder and lightning*," and the celebrated Abbé Nollet, in his *Leçons de Physique*, acutely described many great points of resemblance between them. "If any one (he observes) should take upon him to prove from a well connected comparison of phenomena, that thunder is, in the hands of nature, what electricity is in ours,—that the wonders we exhibit at our pleasure are little imitations of those great effects which inspire us with awe, and that the whole depends upon the same mechanism, if it is to be demonstrated that a cloud prepared by the action of winds, by heat, &c., is an electrised body,—I avow this idea, well supported, would be to me a source of great delight."

At length Franklin in America, and several philosophers in France, conceived the grand thought of bringing the element of lightning out of the atmosphere, by means of pointed conducting bodies; and in the year 1752 electrical sparks were drawn from the clouds. Tired of waiting for the erection of a spire at Philadelphia, on which he proposed to fix a pointed rod of iron, the American philosopher had recourse to a common kite, as affording an immediate and ready access to the region of lightnings. . The kite had a pointed wire, and the twine which held it was attached to an insulating cord of silk. A passing shower opportunely wetted the twine, and increased its conducting power,—at the same moment electrical sparks were drawn from a key hung on the extremity of the kite-string.

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* Dr. Wall also observes, *Phil. Trans.*, vol. xxvi., that the crackling sound and light produced by the excitation of amber represents in some degree thunder and lightning.

In the mean time, Dalibard and Delor, both zealous partisans of Franklin, had drawn electrical sparks from the clouds at Paris and in its vicinity, by means of pointed iron rods, forty feet in length, elevated upon some of the highest ground they could find; and thus was verified one of the most interesting and important theories to be found in the history of physics.

19. Dr. Franklin, in remarking on the similarity between common electricity and lightning, cautions his readers against any degree of disparity of effect as an argument against the identity of these powers. It is no wonder, he says, that the effects of the one so far surpass the other. "If two gun-barrels, when electrified, will strike at two inches distance, and make a loud report, at how great a distance may 10,000 acres of electrified cloud strike, and how loud must be that crack?"

The great points of coincidence between the common electric discharge and lightning may be thus specified:—

Flashes of lightning are frequently waving and crooked, of a zig-zag or forked appearance, sometimes diffuse and coloured—the same is true of sparks drawn from the ordinary electrical machine.

Lightning most commonly falls on elevated or pointed objects—the same is true of electricity.

Lightning seizes on the readiest and best line of transit in its course to the earth—the same is true of the common electrical discharge.

Lightning burns up various kinds of matter—fuses and ignites metallic bodies—the same is true of the electrical discharge.

Lightning rends brittle substances, and scatters various kinds of matter, as if they were acted on by a violent expansive force—such is also the case with electricity.

Lightning impresses on living animals a peculiar nervous shock, and sometimes destroys life,—this is also the case with electricity.

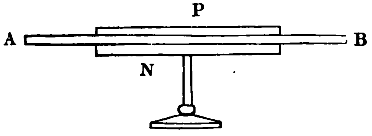
Lightning reverses, destroys, or gives magnetic polarity to steel—such is also the result of powerful electrical discharges.

When these coincidences are considered, together with the fact that electricity may be drawn out of the clouds and air, and applied to produce precisely the same effects as those resulting from a common electrical machine, it becomes quite evident that the cause, whatever it be, of ordinary electrical phenomena, is identical with that of lightning; consequently we arrive at the important deduction, that common electricity and lightning are subject to the same laws,—a deduction which cannot be too forcibly insisted on, involving as it does the most valuable practical consequences.

Nature of ordinary Electrical Arrangements producing Artificial Lightning.

20. The great discovery of the electrical jar, to which we have adverted (17), involves, in fact, all the conditions of a thunderstorm, the disruptive discharge from the jar being the same in effect as thunder and lightning. This will be immediately perceived by referring to what has been already advanced on this subject (10), (11),where it may be seen that the conditions there represented are reducible to the separation of two conducting planes, P, N (fig. 1), by an intermediate insulating substance A; one of the conductors, P, being limited, the other, N, of indefinite extent. Now, to complete such a system artificially, we have only to attach two conducting surfaces, P, N (fig. 6), to the opposite sides of a square of glass, A, B, leaving about an inch of the glass clear and projecting between the two. If such a system be placed on a conducting base, communicating with the earth, it is evident we have a limited and insulated conductor, P, opposed to a conductor, N, of indefinite extent. Directly we charge this system on the insulated surface, P, the two conducting surfaces, P N, become the terminating planes of a great electrical action, and the particles

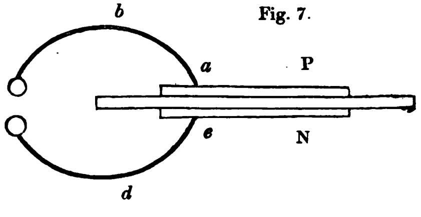
Fig. 6.



of the glass become polarized by induction (11): hence this system is precisely the same as that represented in fig. 4. The nature of the insulating substance between the planes, does not in any way interfere with the conditions of this arrangement, nor does its thickness, because induction goes on at all distances. Faraday traced it from a small electrified ball in the middle of a room to the walls, twenty-six feet distant*. It takes place, however, with the same constraining force, more readily according as the extent of the intervening insulation is lessened. Hence it is, that with a small thickness of glass we obtain a very intense action, the density and compactness of the glass furnishing a resistance, sufficient to maintain the particles in their polarized condition. This is not the case with a gaseous insulation, such as air, the particles of which soon break down at small distances, under the reactive force of the opposite electrical powers (11) (13).

21. It is, however, requisite here to understand, that disruptive discharges from this arrangement are generally obtained by neutralizing the forces through a side circuit of conductors; that is to say, instead of allowing the intermediate glass to become broken

Fig. 7.



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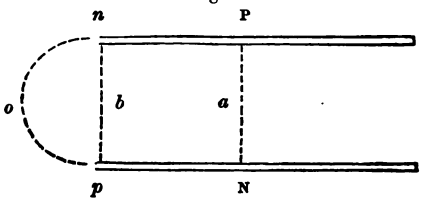
* *Researches in Electricity*, p. 411.

down by the force between the conducting planes, P, N, as supposed in figs. 1 and 4, we discharge the system through a side circuit, *a b c d e* (fig. 7). This, however, is of no consequence to the result of this experiment, because the laws of such discharges, by which the system is reduced to electrical quiescence, remain the same; and any substance exposed to the effects of the discharge in the interval, *c*, would be affected in precisely the same way as if it were in the interval, P, N, immediately between the terminating planes.

Thus, suppose P N (fig. 8), to be the terminating planes of a great electrical disturbance in an interval

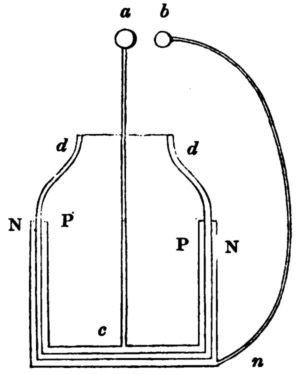
Fig. 8.



of air. Imagine a conducting path suddenly opened, and the system discharged: it is clear that whether such a path were opened immediately between the planes as at P *a* N, or at the edge of the planes as at *n b p*, the result must be the same. Now, imagine the conducting circuit at the edge of the planes to be curved into the form *n o p*, still this could not possibly affect the law of the discharge in the circuit,—but this last is the case in question. Suppose, further, we had made a disruptive interval in this discharging conductor in any point of it, as at *o*, *b*, *a*, still the result of the discharge in such an interval would remain invariable; consequently we may assume any one of the three paths of discharge, P *a* N, *n b p*, *n o p*, to be a casual association of bad and good conductors, as in the case of a building, without in any way affecting the law of the discharge through them. Therefore let the immediate position of the line of discharge be what it may, whether immediately between the planes P, N, or extending without them as at *n o b*, or whether interrupted by a large interval P *a*, *n b*, *n o*, still the laws regulating the neutralization of the opposite electrical forces through such a disjointed circuit must be always the same.

22. Then, with respect to the immediate mechanical form or arrangement of such a system, that is also a matter of indifference; we may make the system cylindrical if we please, and hence the immediate application of the principle to the Leyden experiment or electrical jar. This piece of electrical apparatus in its improved state, consists of two conducting surfaces P, N (fig. 9), pasted on the opposite sides of a glass jar, a portion of the glass *d d* being

Fig. 9.



left clear and projecting between them. When electricity is communicated to the interior insulated surface P, by means of a rod *a c*, the outer surface N resting on the ground, the whole system becomes charged as in the former case, and may hence be in like manner discharged by means of a curved metallic wire *n b*, and if we connect the charging rods of many such jars, all resting on a common conducting base, we may charge and discharge the whole together, as one great system of enormous power, and produce effects approaching to those of lightning. With the great battery in the Tylerian Museum at Haerlem, which exposed 225 square feet of insulated metallic surface *d*, Van Marum gave polarity to steel bars nine inches long, nearly half an inch wide, and one-twelfth of an inch thick. A piece of box-wood four inches in diameter and four inches in length was rent by it in pieces. It melted readily various metals, and dispersed them in all directions. An iron wire twenty-five feet long, and about $\frac{1}{140}$th of an inch in diameter, fell under the shock, into red hot balls dispersing in all directions. A piece of tin wire eight inches long, and one-eighteenth of an inch in diameter, disappeared in a cloud of blue smoke, throwing down red-hot globules of tin, which repeatedly rebounded from a piece of paper beneath it*. In the course of similar experiments by Mr. Brook, he says, "the report was so very loud, that our ears were stunned, and the flash of light so very great, that my sight was quite confused for a few seconds."

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* Roz. xxxiii. and *Phil. Mag.*, vol. viii.; NICH. ii, 527.

The electrical machine employed by Van Marum consisted of two circular plates of glass, each five feet five inches in diameter: these were set on the same axis, and were rendered electrical by revolving with friction between eight cushions, each about fifteen inches long, and two inches wide. The power of this splendid instrument was such, that bodies at forty feet distance were sensibly influenced; pointed wires became tipped with a star of light at twenty-eight feet distance (14), and a powerful current of brilliant light two feet or more in length, crooked, and darting forth luminous brushes into the air, was obtained by presenting a metallic ball in connexion with the earth, to its great conductor. A single spark melted a considerable length of gold-leaf, and fired various kinds of combustibles.

We have thought it not unimportant to notice these results, as having a direct bearing on the great question of the defence of buildings from lightning. For since the accumulation of electricity by artificial means may be carried to an almost indefinite extent, and is equally manageable, whatever may be the extreme limit of force we choose to assign to such accumulation,—it necessarily follows that discharges of atmospheric electricity may be quite as easily directed, by a judicious and scientific arrangement of conducting bodies; such discharges being in fact, nothing more than the same force also resulting from a species of electrical machine, and accumulated in a similar way, by means of an apparatus of a perfectly similar kind. The vapoury masses of the clouds, opposed through the intermediate air to the surface of ground or sea, constitute a battery of enormous power. The circumstance of the coatings of the jar being metallic, whilst those in nature consist of water, is a difference of no moment whatever; especially when we consider that the original experiment of the Dutch philosophers, consisted in the electrification of water inclosed in a small phial, from which they obtained so great a shock, as to induce one of them to say that he would not again receive it for the whole kingdom of France.

Various Phenomena of Lightning and Thunder.

23. The identity of ordinary electrical discharges with the phenomena of thunder and lightning being thus satisfactorily shown, we have now merely to consider some of those modifications of the effect, characteristic of these great natural operations In the first place, it is to be observed, that when the discharge takes place very close to the observer, the effect is a brilliant vivid light of momentary duration, intolerable to the eye, and attended by a terrific and sudden whizzing crash, as if ten thousand porcelain jars had fallen on a stone pavement, and were smashed in pieces. When however, some considerable distance is interposed, the light is more tolerable, and precedes the crash by a sensible time; in this case the noise begins to soften down into a sort of reverberating roar; at still greater distances the

reverberations are taken up, and bandied about between the irregular forms of the distant clouds and the surface of the earth, producing what has been termed, in common language, peals of thunder. A similar effect ensues on the earth's surface, during the discharge of cannon, where surrounding objects present irregular sources of reverberation: on the sea, where so few obstacles to the diffusion of sound exist, distant thunder regularly dies away in a sort of sullen silence. The distance of the point of discharge, may be estimated by the time which elapses between the flash of lightning and the thunder; since for small distances, the progress of light may be taken as instantaneous: sound, on the contrary, has a more sensible duration, being propagated through the air, at the rate of eleven hundred feet in a second. It may be here remarked, that an essential distinction exists between the *light* of lightning, for which, as Franklin observes, we want an appropriate term, and the presence of the electrical agency itself.

24. Arago divides the phenomena of lightning into three classes. In the first he places those luminous discharges characterized by a long streak of light, very thin, and well defined at the edges: they are not always white, but are sometimes of a violet or purple hue; they do not move in a straight line, but have a deviating track of a zig-zag form. They frequently divide in striking terrestrial objects, into two or more distinct streams, but invariably proceed from a single point.

The Abbé Richard witnessed a discharge of this kind descend from a cloud, and divide upon two separate objects on coming near the earth*. We have instances, in the damage done to our shipping, of the trifurcation of lightning, in which the three masts of a ship have all been struck by the same discharge. This result ensued in His Majesty's ship *Implacable*, under the command of Sir George Cockburn, in July, 1810, near the Isle of Wight. The fore and mizen top-gallant masts were shivered, and traces of the discharge were left on the main mast.

Under the second class, Arago has placed those luminous effects not having any apparent depth, but expanding over a vast surface: they are frequently coloured red, blue, and violet; they have not the activity of the former class, and are generally confined to the edges of the cloud from which they appear to proceed.

The third class comprises those more concentrated masses of light, which he has termed globular lightning. The long zig-zag and expanded flashes, exist but for a moment, but these seem to endure for many seconds: they appear to occupy time, and to have a progressive motion.

25. It is more than probable, that many of these phenomena are at last reducible to the common progress of the disruptive discharge, modified by the quantity of passing electricity, the density and condition of the air, and the brilliancy of the attendant

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* *Histoire Naturelle de l'Air et des Météores.*

light. When the state of the atmosphere is such, that a moderately intense discharge can proceed in an occasionally deviating zig-zag line, the great nucleus, or head of the discharge, becomes drawn out as it were, into a line of light visible through the whole track; and if the discharge divides on approaching a terrestrial object, we have what sailors call forked lightning. If it does not divide, but exhibits a long rippling line, with but little deviation, then they call it chain lightning. What sailors term sheet lightning, is the light of a vivid discharge reflected from the surfaces of distant clouds, the spark itself being concealed by a dense intermediate mass of cloud, behind which the discharge has taken place. In this way an extensive range of cloud may appear in a blaze of light, producing a truly sublime effect. The appearance termed globular lightning, may be the result of similar discharges; it is no doubt always attended by a diffusely luminous track, this may, however, be completely eclipsed in the mind of the observer, by the great concentration and density of the discharge, in the points immediately through which it continues to force its way, and where the condensation of the air immediately before it is often extremely great. It is this intensely illuminated point which gives the notion of globular discharge; and it is clear, from the circumference of air which may become illuminated, the apparent diameter will be often great. Mr. Hearder, of Plymouth, once witnessed a discharge of lightning of this kind on the Dartmoor hills, very near him. Several vivid flashes had occurred, before the mass of clouds approached the hill on which he was standing: before he had time to retreat from his dangerous position, a tremendous crash and explosion burst close to him. To use his own words, "the spark had the appearance of a nucleus of intensely ignited matter, followed by a flood of light; it struck the path near me, and dashed with fearful brilliancy down its whole length, to a rivulet at the foot of the hill, where it terminated."

Appearances termed Fire Balls.

26. A great deal has been said relative to these appearances, and some doubts have been entertained of their real existence as mere balls of electrical light. Nevertheless the evidence of the existence of a form of disruptive discharge, faithfully conveying to the observer such an impression, is beyond question. A curious instance is given by Mr. Chalmers whilst on board the *Montague*, of seventy-four guns, bearing the flag of Admiral Chambers. In the account read at the Royal Society*, he states that "November 4th, 1749, whilst taking an observation on the quarter-deck, one of the quarter-masters requested him to look to windward; upon which he observed a large ball of blue fire rolling along on the surface of the water, as big as a mill-stone, at about three miles distance. Before they could raise

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* *Phil. Trans.*, vol. XLVI., p. 366.

the main-tack, the ball had reached within forty yards of the main-chains, when it rose perpendicularly with a fearful explosion, and shattered the main top-mast in pieces." In an account of the fatal effects of lightning, in June, 1826, on the Malvern hills, when two young ladies were struck dead, it is stated that the electric discharge "appeared as a mass of fire rolling along the hill towards the building in which the party had taken shelter*."

The great number of accounts of such appearances, and the remarkable coincidences in them all, extending as they do through nearly a whole century, and consequently given by observers in no way connected with each other, leave not the least doubt of their existence. M. Deslandes transmitted to the Academy of Science in Paris an account of a terrible thunderstorm in Britanny, in April, 1718, which completely destroyed a church near Brest. In this account it is stated that the damage was done by three large globes of fire of three feet and a half in diameter, which fell at once on the spire†.

It is by no means easy to explain these appearances on the principles applicable to the ordinary electric spark: the amazing rapidity with which this proceeds, and the momentary duration of the light (6), renders it almost a matter of impossibility that the discharge should appear under the form of a ball of fire; it would be a transient line of light: we must look, therefore, to some other source for an explanation of these appearances.

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* *Loyd's Evening Post.*

† *Annuaire* pour 1838, p. 259.

Now it is not improbable, that in many cases in which distinct balls of fire of sensible duration have been perceived, the appearance has resulted from the species of brush or glow discharge already described (14), and which may often precede the main shock: the ball of fire, observed by M. Toscan at the Botanic Gardens in Paris was evidently a result of this kind. In short, it is not difficult to conceive, that before a discharge of the whole system takes place, that is to say, before the constrained condition of the dielectric particles of air intermediate between the clouds and earth (11) becomes as it were overturned, the particles nearest one of the terminating planes, or other bodies situate on them, may begin to discharge upon the succeeding particles, and make an effort to restore the neutral condition of the system by a gradual process. Such was doubtless the case in the instances given by M. Deslandes and M. Toscan.

If therefore we conceive the discharging particles to have progressive motion from any cause, then we shall immediately obtain such a result as that observed by Mr. Chalmers on board the *Montague* (26), in which a large ball of blue fire was observed rolling on the surface of the water, towards the ship from *to windward*. This was evidently a sort of glow discharge, or St. Helmo's fire, produced by some of the polarized atmospheric particles yielding up their electricity to the surface of the water, much in the same way, as in the appearance observed by M. Toscan, the stationary cloud did on the land. The clouds, however, were here in rapid motion, the ship at the time being under topsails and courses only, in consequence of the strength of the wind: the discharging particles, therefore, had motion towards the ship, the rate of which, appears from the account, to correspond with the velocity of the breeze. On nearing the ship, the point of discharge became transferred to the head of the mast; and the striking distance being thus diminished, the whole system returned to its normal state (10), that is to say, a disruptive discharge ensued between the sea and the clouds (11), producing the usual phenomena of thunder and lightning, termed by the observers, the "rising of the ball through the mast of the ship." The fatal occurrence on the Malvern Hills (26) is another instance of the same kind. A similar effect, is described in the *Phil. Trans.* for 1773, in which a ball of light appeared in the parlour of a house struck by lightning at Steeple Ashton. The ball is described as being of "the size of a sixpenny loaf, and surrounded with a dark smoke," and is said "to have burst with a loud noise." This too was evidently a species of brush or glow discharge (15), preceding the stroke of lightning which damaged the house.

It is therefore highly probable, that all these appearances so decidedly marked as concentrated balls of fire, are produced by the glow or brush discharge producing a St. Helmo's fire in a given point or points of the charged system, (11), previously to the more general and rapid union of the electrical forces; whilst the greater number of discharges described as globular lightning, are, as already observed, most probably nothing more than a vivid and dense electrical spark in the act of breaking through the air,—which, coming suddenly on the eye, and again vanishing in an extremely small portion of time, has been designated a ball of light. Thus in a thunderstorm which damaged a house at Eastbourne, in Sussex, in September, 1781, balls of fire were said to dart from the clouds into the sea. These were evidently common electrical sparks seen at a distance; for when the lightning struck the house, "multitudes saw the meteor dart in a right line over their heads, and all agreed that the form and flame were exactly like that of an immense sky-rocket*."

Sulphurous Odour of the Electric Discharge.

27. There is one circumstance noticed by the celebrated Italian philosopher, Beccaria, which must not be lost sight of, as having doubtless great influence over these appearances, viz., the tendency of the electrical discharge to drag into its path light conducting substances, which can facilitate its progress, and by which it is enabled to strike through

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[*] *Phil. Trans.* for 1781, p. 42.

distances considerably greater than would otherwise be traversed. Thus traces of smoke, free vapour, or any other conducting matter floating in the air, will frequently determine the course of lightning, and not only determine it as to direction, but greatly modify its appearance. A heated or whirling column of air, such as is sometimes seen to arise even in a tranquil state of the weather, would produce a similar effect through its interior and rarefied portion; and there is little doubt that conducting matter, when dragged into the path of lightning, would be intensely heated and decomposed. Beccaria once received an electric shock through the fumes of nitric acid, which became concentrated and driven into his thumb, producing a small round hole; and Priestley found that a discharge could be produced, by the dispersion of a drop of water which hung on a brass rod communicating with the inside of his battery.

The transfer and ignition of ponderable matter through the track of electrical discharge, may be adduced, to explain in some degree, the suffocating sulphurous odour so frequently observed at the time of heavy strokes of lightning: on ship-board more especially, when great damage has arisen, and the electrical discharge has exploded below decks, this sulphurous smell is described as quite suffocating. In the case of the *Montague*, just cited (26), it is said of this odour, that " the ship seemed to be nothing but sulphur." From whence this arises is still an interesting problem in physics. There are many facts, which favour the idea of various kinds of matter being dragged and transported into the track of the electrical discharge, either immediately from the body of the earth, or from the atmosphere in which they are often found; and it is not impossible in this way, to explain those apparently solid balls of fire termed more especially meteors: that vapours of various kinds may greatly modify and direct disruptive discharge, is unquestionable, and hence give rise to those long truncated appearances of flame frequently observed in discharges of lightning. It would be trespassing on the limits of this work, to enter at length upon the theory of meteors, or upon those chemical views which some able philosophers have entertained, of the nature of the odour emitted by the electrical discharge; it may perhaps be sufficient for our present purpose to keep it in view, without an elaborate detail of its possible causes*.

Artificial Disruptive Discharges.

28. The luminous appearances observable in the great and terrible discharges of lightning, may be completely obtained by artificial means, giving rise to experiments of a highly instructive kind. The

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* Mr. Benjamin Cook, F.R.S., states, that after a night of vivid lightning, with thunder, an oblong ball, of a bright yellow colour, and frosted over with fine yellow crystals, was found in a meadow far from any house, and in a perfectly undisturbed surface of ground. The ball appeared quite fresh. The crystals were easily displaced, and the matter of the ball was principally sulphur. It burned with mild sulphurous flames.—*Phil. Trans.*, vol. XL.

conditions which modify the extent and appearance of the electrical discharge, produced artificially; are the form and extent of the conductors,—between which the disturbance has taken place, the quantity of accumulated electricity, the intensity of the charge, and the nature and density of the medium through which it forces its way. Between round and even surfaces, of considerable extent as compared with the amount of electricity accumulated, the sparks, under common states of the air, are short and dense, approaching in appearance globular lightning: and this is true in respect of electricity passing between any two parallel surfaces, and is even applicable to the conditions of the discharge of the electrical jar. The opposed conductors P N (fig. 7), so influence the form, appearance, and dimensions of the spark, that we cannot obtain under common circumstances, through the neutralising circuit *abcde*, a more extensive discharge than could take place, supposing it to have occurred immediately between P N, the terminating planes themselves. Short dense discharges are in each case produced, approaching in appearance to many of those in nature, called by sailors, fire-balls.

By changing the disposition and form of the conductors, we obtain longer and more diffuse sparks, of a zig-zag and waving character, which frequently bifurcate, and otherwise divide, producing appearances similar to those termed by mariners, forked and chain lightning. All this greatly depends on the activity of the charge, which again varies with the extent of surface upon which it passes; the activity of electricity disposed on surfaces varying in dimensions, being in an inverse duplicate ratio of the surface, the quantity being constant*; that is to say, a given quantity of electricity collected on a double extent of conducting surface, has only one-fourth the activity, on a treble extent only one-ninth, and so on. Hence an electrical disturbance which between terminating planes of large dimensions, would be comparatively quiescent, becomes active and unruly between planes of much less extent. When large quantities of electricity therefore, press upon small surfaces, the spark is elongated and spiteful in its character, and if these be indefinitely reduced to mere points, the discharge is narrowed into a sort of stream, causing a rapid escape of the electricity under such an attenuated form, as to produce a comparatively tranquil and gradual discharge (14). It is, as observed by Faraday when treating of this curious action of pointed conductors, at the extremity of a point, that the intensity necessary to charge the air is first acquired; from thence the particles recede. At the same time the point, having become the origin of an active mechanical force, does, by the very act of causing that force, namely by discharge, prevent any other part of the conducting body from which it projects, from acquiring the same condition, and thus preserves its own predominance. In this way pointed conductors operate in discharging large accumulations at considerable distances, under the form of stream, brush, or glow, and so parry the violent concentrated explosion commonly attendant on them. This result ensues whether the pointed conductor be affixed to the charged body or not, the opposite electrical state being always produced in every case of discharge. Thus, if we present a pointed metallic body to the conductor of the machine, in the act of throwing off dense and brilliant sparks, such sparks can no longer be obtained (8).

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* *Phil. Trans.* for 1834, p. 221.

29. Brush discharge exhibits a great variety of character in different media, its colour, form, and sound, being all greatly modified, according as it takes place on a positive or negative surface. Nitrogen gas, which enters in the proportion of four-fifths into the composition of the atmosphere, has the greatest power of originating this kind of discharge. The brushes in this gas, are always fine in form, light, and colour; and in nitrogen rarefied by the air-pump the effects are still more striking.

Brush discharge in air from a positive point (11) is frequently diffuse and spreading, producing the appearance called by sailors comazants, or St. Helmo's fires: from a negative point (11) it has often the character of a luminous star, exhibiting the appearances mentioned by Pliny and other ancient writers (15).

When the air in contact with a metallic conductor is rapidly charging, the end of the conductor will often become covered with a glow of lambent light, producing a peculiarly beautiful appearance; this is greatly increased either by decreasing the atmospheric pressure, or by augmenting the electrical force. Faraday produced on a brass ball within an exhausted receiver, a glow of light over an area of two inches. The glow came over the ball, and gradually increased in brightness until it was at last very luminous, and stood up like a low flame of half an inch or more in length*, being analogous to one of the natural phenomena already mentioned (15).

30. When the discharge is assisted by traces of conducting matter, it will traverse very considerable distances. Thus a trace of sulphuric acid, or small particles of charcoal, or metallic dust, dispersed over a strip of glass, will enable a battery to produce a brilliant and intensely luminous discharge, over a considerable distance. A trace of smoke will in like manner facilitate the progress of the explosion. When the intermediate air is highly rarefied in a tube of glass, a jar may be discharged through it to the extent of several feet, sometimes in one dense mass, in others producing bifurcations and various coloured streams.

In the vacuum of a well-boiled barometer, the electrical light is frequently of a beautiful green colour, and in media of different kinds varying in density, the colour of the spark is altogether changed. Thus in carbonic acid gas it is white and vivid, in hydrogen gas it is red and faint. All this again becomes modified by the quantity of electricity, and by the kind and form of the conductors from which it takes place. Considering, therefore, all these circumstances, it is not at all surprising, that we find lightning assuming so great a variety of appearance.

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* *Experimental Researches*, p. 47.

Further Observations on Thunder Clouds.

31. Although the disruptive discharge of thunderstorms, commonly proceeds at once through the air intermediate between the charged clouds and the earth, yet other more complicated discharges have been supposed to occur, in consequence of electrical disturbances between distinct and distant portions of the atmosphere, in which the surface of the earth becomes involved as a line of discharge between them. The Italian philosopher, Beccaria, entertained opinions of this kind; he seemed to consider it impossible, that any cloud or collection of clouds, should contain the great quantity of electricity observed in thunderstorms, so as either to discharge or receive it. He states that during the progress of a storm, although the lightning frequently struck the earth, yet the clouds were the next moment ready to make a still greater discharge; and hence he concludes that "the electrical matter is continually darting from the clouds in one place, at the same time that it is discharged from the earth in another." The knowledge however we now possess, of the nature and extent

of electrical action, renders it quite unnecessary to resort to such hypothetical views, in order to explain this phenomenon. The immense absorption and evolution of electricity attendant on chemical and other changes in common matter, is quite sufficient to account for the apparently great quantity of electricity, active in thunderstorms.—Faraday has shown by strong experimental evidence, that the quantity of electricity holding the elements of a single grain of water in chemical combination, is equal to that discharged in an ordinary flash of lightning, and would, if discharged under the form of a current through a wire of platinum about $\frac{1}{104}$th of an inch in diameter, keep it red-hot in the air, for nearly four minutes*. The simple view therefore, which we have taken of the electrical conditions of a thunderstorm, is in no way embarrassed by any difficulty arising out of the great quantity of electricity liable to be discharged. Besides, it is not clear that the quantity is so great in relation to conducting bodies, as might at first be supposed. It is to be recollected, that we often judge of the quantity of electricity present, by very deceptive effects,—as by the light of the spark, the noise and expansive force of the discharge, and by the damage done to imperfect conducting matter. Now, we have seen (22) that comparatively small quantities of electricity will produce intense effects of this kind; and it is doubtful whether any quantity of electricity ever discharged in a single flash of lightning has been sufficient to melt a copper rod a foot in length and three-fourths of an inch in diameter.

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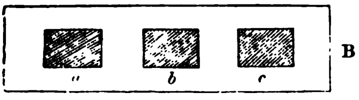
* *Experimental Researches in Electricity*, p. 250.

32. The general condition of a thunderstorm is, as already observed (4), the charging and discharging of a stratum of air intermediate between the masses of cloud and the earth, or otherwise intermediate between two masses of clouds in opposite electric states; the source of the charge being the evolution of electricity in consequence of certain physical changes in the state and condition of the atmosphere. Discharges of lightning produced by this state of things, may arise during the formation or presence of clouds in a given place, or during their formation and motion through the air, by which a large stratum of polarized particles is swept along over the earth's surface; or they may arise from the motion of an upper current of cloud over a large track of atmosphere, which has from any previous train of circumstances, become polarized; or otherwise, from the operation of successive superimposed strata of air and clouds, reaching to the surface of the earth; or otherwise from the operation of distant and distinct portions of the atmosphere, oppositely charged, and which may hence discharge into each other, under a great variety of conditions.

33. We are indebted to Franklin for a most ingenious analysis of the Leyden experiment, applicable to many of the cases above mentioned. He has shown that the opposed metallic surfaces P N, in either of the arrangements (figs. 6 and 9), merely

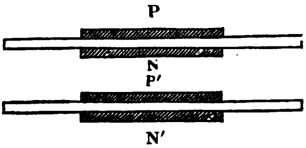
operate as conductors to the charge; and that the charge once accumulated, the original coatings may be removed, and other coatings applied, so as to discharge either the whole, or successive portions of the system. Thus supposing A B (fig. 10) to be a charged stratum of glass from which one of the charging surfaces has been removed; then by applying other coatings of less dimensions in the points *a b c*, the glass may be discharged in these portions successively.

Fig. 10.



It may be further shown, that in the case of two near but distinct systems, P P′ (fig. 11), one of these may be charged from the other, and then be discharged, either separately or through each other.

Fig. 11.



That is to say, if from any cause electricity be evolved on P, the opposite state will be produced in the terminating plane N, producing discharges upon P′, and so again inducing the opposite states or forces in P′ N′, and these systems may be so circumstanced, as to produce disruptive discharges by means of each separately, or by them both at once.

Lastly, if two systems P P′ (fig. 12) be charged oppositely, that is to say, if the system P N have the positive force P in an opposite surface to the positive surface P′ of the system P′ N′, then these systems may be so circumstanced, as to discharge through each other, by any conducting or semi-conducting matter joining N P′ and P N′.

Fig. 12.

Stationary Disturbances.

34. Thunderstorms arising out of a rapid formation of vapour, and in a limited portion of the air, as illustrated in fig. 1 (10), have been well described by Beccaria. "The first appearance of a thunderstorm," he says, "generally happens when there is little or no wind; there is one dense cloud or more, increasing very fast in size, and rising into the higher regions of the air. The lower surface is black, and nearly level, but the upper is finely arched, and well-defined. Many of these clouds seem piled one over another, all arched in the same way, but they keep continually uniting, swelling, and extending their arches. At the time of the rising of this cloud, the atmosphere is generally full of a great number of separate clouds of whimsical and irregular shapes, and apparently motionless. All these upon the appearance of the thundercloud draw towards it, become more uniform in their shape, and at length form with it one common mass.

Sometimes the thundercloud will swell very fast without the conjunction of such clouds, and when it is grown to a great size, its lower surface is frequently ragged, and swells into large protuberances which bend uniformly toward the earth; sometimes one whole side of the cloud has an inclination toward the earth. When the eye is under the thundercloud, it is at last seen to darken fearfully, and a number of small clouds, the origin of which is never detected, drive about it in uncertain directions. Rain and hail about this time fall in abundance. During the swelling and extension of the cloud over a large tract of country, lightning darts through its mass, and at length strikes toward the earth in opposite places; the longer the lightning continues, the rarer the cloud becomes, till at length it breaks up in different places, and shows a clear sky*."

Captain Ward, R.N., gives the following interesting account of the phenomena observed by him during a thunderstorm in the Bay of Honduras in the West Indies, whilst he was in command of His Majesty's ship *Pelican*, in the autumn of the year 1806. "The night was nearly calm, and the heat oppressive; heavy black clouds intensely charged with the electric fluid, overspread the earth, and about midnight, after a little whirl of wind, began to approach it. A discharge of lightning of the most splendid, and at the same time most awful character, speedily ensued. The electric fluid seemed to pour down upon the earth and sea in repeated streams, occasionally illuminating everything about us with a brilliancy surpassing noon-day, but leaving us at the next instant in pitchy darkness. This fearful display, attended by roaring peals of thunder, lasted about an hour, during which time one of the discharges fell on our main-royal mast-head, shivered it, together with the top-gallant mast and topmast in atoms, scattering the fragments to an immense distance, so that not a piece of any size could be found. The discharge continued its course with damage along the main-mast in an irregular spiral form down to the very heel and step of the mast, where it disappeared."

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* *Lettere dell' Elettrismo*, p. 151 to 167.

One of the most awful accounts, however, of a thunderstorm at sea is that given by an intelligent observer, present as a passenger in the splendid American packet-ship *New·York,* which was struck and damaged by lighning in the Gulf-stream, April 19th, 1827, in her passage from New York to Liverpool. "About half-past five in the morning, being in our berths, we were roused by a sound like the report of heavy cannon close to our ears. In a moment we were all out. From the deck the word was quickly passed that the ship had been struck by lightning, and was on fire. Every one ran on deck; there, all the elements were in violent commotion: it had been broad day, but so dark, so dense, and so close upon us were the clouds, that they produced almost the obscurity of night. There was just sufficient light to give a bold relief to every object in the appalling scene; the rain poured down in torrents, mingled with hailstones as large as filberts: these lay upon the deck nearly an inch thick; overhead blazed the lightning on all sides, accompanied by simultaneous reports; the sea ran mountains high, and the ship was tossed rapidly from one sea to another. One appearance was peculiarly remarkable: the temperature of the water was 74° of Fahrenheit, whilst that of the atmosphere was only 48°. This caused by evaporation and condensation, immense clouds of vapour, which ascending in columns all around us, exhibited the appearance of innumerable pillars supporting a massive canopy of clouds. In all directions might be seen water-spouts, which rising fearfully to the clouds, seemed actually to present to the eye a combination of all the elements for the destruction of everything on the face of the deep." These accounts afford highly instructive examples of the spontaneous evolution of electricity in the atmosphere, giving rise to a vast electrical disturbance, and subsequent disruptive discharges (11).

35. The altitude of the masses of cloud, forming the upper terminating plane of the electrified system, does not appear to be so considerable as their horizontal dimensions, which not unfrequently extend over a large tract of country, producing almost simultaneous discharges in various places. Admiral Ross states, that the storm which shivered the masts of the *Désirée* in Port Antonio, Jamaica,

in the autumn of 1803, was witnessed by an observer some short distance up the adjacent hill. It appeared to take place close under him, during a fine clear star-light evening overhead.

On the night of the 14th of April, 1718, a thunderstorm occupied the coast of Britanny between Landerneau and St. Pol de Leon, and damaged no less than twenty-four church towers*. In 1774 a severe thunderstorm spread itself over London. The lightning damaged St. Peter's church considerably, and at the same time several other discharges occurred in various places far distant from each other. A Dutch ship in the river off the Tower was struck, also the obelisk in St. George's fields, Southwark, together with a chimney at Lambeth, and a house at Vauxhall†. On the 11th January, 1815, another thunderstorm occupied no less a space than that contained between the North Sea and the Rhenish provinces, and severely damaged twelve church towers in various parts of this extensive tract‡.

36. The electrical disturbance is sometimes so very rapidly progressive, that repeated discharges are observed to occur in the same place, in quick succession. The church and buildings of the abbey of Nôtre Dame, in the town of Ham, in France, was, during the night of the 25th April, 1760, struck three times in the short interval of twenty minutes,

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* *Annuaire* pour 1838, p. 479.

† *Phil. Trans.*, vol. LXIV. for 1774.

‡ *Annuaire* pour 1838, p. 481.

and the whole burnt to the ground*. His Majesty's ship *Hyacinth* had first her fore-top mast, then her main-top mast rent in pieces by two discharges which followed close upon each other†.

His Majesty's ship *Madagascar*, in coming to an anchor in the Corfu Channel, in January, 1829, was struck by lightning no less than five times within two hours; the sails were set on fire, and other damage done. His Majesty's ship *Ætna* was in the same storm, and not far distant; she experienced repeated discharges: "the descent of the electric fluid was frequent and at very short intervals‡."

Discharges produced by the Motion of Clouds.

37. Before noticing explosions of lightning liable to occur during the progressive motion of clouds, it may not be out of place to describe a few simple experiments derived from Franklin's analysis of the Leyden jar, illustrative of the general principles on which they may be supposed to depend.

The experimental arrangement is represented in fig. 13, in which A B is an oblong plate of some good insulating substance, such as glass, resin, or brimstone, about two feet or more in length, and ten inches wide; N is a similar plate of wood covered with tin-foil, and placed beneath the insulating plate A B, so as to support it about an inch above a conducting table C D; about two inches of the glass are left clear at the edges; P is a light plate of wood also covered with tin-foil about six inches square, moveable upon the upper surface of the insulating plate A B, so as to place any portion of the glass between the conducting surfaces P N. This upper plate carries a small conducting tube *m*, moveable with friction within a second tube P fixed to the plate. The tube *m* terminates in an insulating handle of glass *t*, and supports a bent cross rod *p o y*, sufficiently long to project over the side of the glass, having at the bent extremity a discharging ball *y*, and at the other the small balls of pith hung loosely on cotton threads. Now, in this arrangement, we may take the inferior conducting plane N to represent the surface of the earth, the moveable plate P a mass of cloud, and the insulating plate A B intermediate between the two, the intervening air (10).

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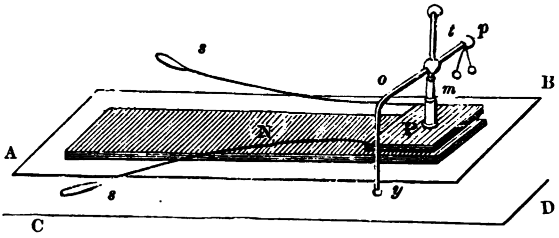
* *Annuaire* pour 1838, p. 482.

† *Report of Commission*, p. 75.

‡ Idem, p. 87.

Fig. 13.



Exp. (*a*). Electrify the plate P until the balls *p* have a full divergence, and draw it in this state along the surface of the glass by the varnished silk lines *s s* until it reaches the opposite extremity. It will then be perceived that its charge will have become more or less distributed over the surface of the glass, and the balls *p* will have nearly closed.

(*b*). Everything remaining as before, depress the cross arm *p y*, by means of the attached glass handle *t*, until the ball *y* is within a short distance of the conducting plane on which the whole rests. Let the silk lines *s s* be reversed, and again draw the plate back to its former position: small disruptive discharges will take place from the ball *y*, by the accumulation of the charge under the plate P as it moves along.

Observation 1. We perceive by Exp. (*a*) that an electrical cloud may polarize portions of the air through which it moves, and become at last quiescent, or nearly so. Exp. (*b*) shows, that masses of cloud moving through a polarized air, may produce disruptive discharges whenever the intensity of the accumulation can break down the intervening air (11). This last effect is more completely illustrated by charging the whole surface of the glass up to a maximum of intensity, previously to applying the movable plate P: this is readily done by a temporary coating of the same dimensions as the inferior coating N, applied to its upper surface, and removable by an insulating handle fixed to its central part.

Obs. 2. The further we suppose the clouds to travel in a charged atmosphere, the greater becomes the intensity of the accumulation. Hence a cloud at first but little electrified, may, by moving through a weakly polarized air, cause so great a disturbance as to produce explosions upon the surface of the earth, the quantity of electricity discharged being dependent on the distance at which the explosion can occur. It is to be further observed, that the atmosphere itself is frequently in an electrical state, and may so far be in a state to act on passing clouds, or to yield free electricity under any hygrometric change produced in it.

38. The conditions of these experiments (*a*) (*b*) require the air, intermediate between the clouds and earth, to be at rest, and the clouds to maintain a uniform altitude. Although this is only a particular case of a general principle resorted to for the sake of simplicity; still the same reasoning applies to cases, in which both the clouds and the air are in motion. Thus we may conceive a polarized air together with the clouds to sweep along over the earth, completing in various points all the conditions of the disruptive discharge; or we may suppose the one to move with a greater or less degree of velocity than the other; or an electrified cloud may be driven by an upper current, in an opposite direction to that of the current on the earth's surface, as often happens; or it may approach the earth, or other clouds by the common result of electrical attraction between masses; or we may imagine, certain clouds in a given electrical state, to be driven by distant winds into an atmosphere in an opposite state, carrying with them polarized air, so as to produce discharges of oppositely electrified systems, into each other, over the earth's surface; or

finally, we may suppose the upper masses of cloud to be comparatively at rest, and a disturbed atmospheric current to intervene between them. All these are not only possible, but highly probable cases; and some of them admit of demonstration by actual observation. We may here quote a few examples.

39. His Majesty's frigate *Clorinde* was struck and damaged by lightning, on the coast of Ceylon, in the spring of the year 1813. The following is a very clear and circumstantial account of the phenomena, by Captain Briggs, R.N., who commanded the ship. "*The weather was moderate.* About three in the afternoon we observed a dark cloud approaching the ship from the *windward* quarter: this induced me to clew up the topsails. About an hour afterwards, the ship was struck by lightning: the cloud we had observed, was charged with electricity, and had burst on the ship. The mainmast was shivered in pieces; only a wreck remained. Three men were killed, and many hurt."

Now it is clear, that in this instance, the disruptive discharge was caused by the progressive motion of a charged cloud, driven by an upper current, upon a comparatively tranquil air, but possibly in a polarized state, sweeping along with it a portion of charged atmosphere, and accumulating forces, sufficient to make it approach the earth, within a distance at which the forces could neutralize through the intermediate stratum.

The following is a similar instance, related by

Captain Haydon, R.N , in which the whole atmosphere and cloud travelled together in the direction of the wind. " His Majesty's ship *Cambrian*, off Plymouth, February 22, 1799, strong gales and squally; observed a tremendous squall coming down upon us; turned the hands up to clew up the close-reefed topsails. Whilst they were so employed, a ball of fire struck the topmast-head, killed two men and wounded many others. The number taken below amounted to about twenty "

The case of His Majesty's ship *Topaze*, struck by lightning in the West Indies, in July, 1802, is another remarkable instance of this source of disruptive discharge. Captain H. Edwards, R.N., who was in the ship at the time, says, " When off the west end of St. Domingo, about two or three leagues from the shore, we were becalmed. About midnight a light breeze came off the land, bearing a dark isolated cloud; the cloud began to discharge its lightning within an apparently short distance of the ship, and after five or six vividly forked flashes, struck our mizen royal-mast, and passed down the mizen-mast, shivering and rending the spars in its course."

It appears that the light breeze from the shore enabled them to get the ship's head the right way, so as to lay her with her stern to the shore: hence the mizen-mast was the mast first acted on by the cloud

40. A great variety of instances might be quoted, in confirmation of disruptive discharges

being produced on the principles already explained (10): they all differ from the state of things observable in more stationary thunderstorms (34) in this, that whilst in such thunderstorms, there is often a rapid, and continuous series of discharges produced by the spontaneous evolution of electricity in one place: we trace in the progress of highly electrified clouds, deliberate discharges of a passing kind, few in number, in some instances not extending beyond one or two at the furthest.

Electrical disturbances, involving similar conditions, but of a more complicated character, sometimes proceed with continued destructive effects over a long tract of country, the atmosphere appearing to assume, during the progress of the masses of electrified cloud, an intensely charged state. Such storms have been observed to pass from the southern shores of England to the north of Scotland and Ireland. A thunderstorm of this kind, occurred in July, 1827. It began on the south-west coast of Devonshire, on Sunday evening, reached Cheltenham the same night, and Glasgow the next morning, the atmosphere throughout this extent, appearing to undergo a rapid and progressive change*.

Possible Sources of Discharge.

41. The case of electrical discharge over the surface of the earth, caused by oppositely electrified and distant masses of cloud and air, although more hypothetical than the preceding, is still not impro-

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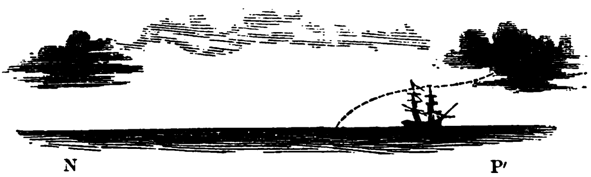
* Provincial and London Journals.

bable. Thus supposing, on the principles already explained (33), P N, P′N′ (fig. 14), were two portions

Fig. 14.



of atmosphere in oppositely charged states, and that from the vicinity of the clouds, P N′, assisted by an intermediate chain of vapour or other matter, these systems could discharge into each other (33), we should have an explosion in the direction N P′, which would extend through the intervals P N, N′P′; and there might possibly arise out of such a condition of things, a luminous discharge between N and P′, in consequence of the neutralization of the opposite electrical forces, over a surface of comparatively small conducting power.

42. But we have here to consider another probable source of disruptive discharge of this kind, termed by the Earl of Stanhope, "The returning stroke." When a great electrical change or disturbance, becomes induced on the surface of the earth, and in various bodies situate on it, as represented in N, fig 4 (11), the result is, an electrical change upon the surrounding surface, extending to considerable distances. Now Lord Stanhope has adduced several experimental facts, in order to show that whenever the forces P N, (fig. 4), neutralize, and violent disruptive discharge ensues; then the dis-

turbed electrical condition of the distant surface, together with that portion of the atmosphere contiguous to it, also returns with violence to its former condition, and may cause, in certain points, destructive electrical action. The following is, he thinks, an instance of this effect. It appears "that two men were proceeding on their carts along a road in Scotland, one of the carts being about twenty-four yards behind the other: suddenly one of the men, James Lander, sitting on the fore-part of the first cart, drawn by two horses, was suddenly struck dead, together with the horses, and the cart severely damaged by electrical fire, although no lightning occurred near the place where the accident happened." The facts of this case appear well authenticated by Mr. Brydone, in a letter to the President of the Royal Society*.

The man on the cart immediately behind Lander had full view of the whole circumstance; he was stunned by a loud report, but saw no lightning Another man also, a shepherd called Cuthbert, witnessed the event at about two hundred and fifty yards distance, whilst looking at the carts.

Mr. Brydone relates, that at this time, he was watching the progress of an electrical storm a great way off, and when the report occurred, was observing by a stop-watch, the time which elapsed before the sound of the thunder reached him.

On examining the wheels of the cart, circular holes were found in the ground immediately under them, about twenty inches in diameter, at which points the iron on the wheels exhibited marks of fusion.

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* *Phil. Trans. for* 1787, p. 130.

His Lordship concludes, that these effects resulted from the discharges of the remote clouds, thereby producing a great electrical commotion in distant bodies; and this effect, he endeavours to show, may arise at many miles distance from the spot over which the thunder clouds appear.

43. The great thickness of the stratum of air, interposed between the clouds and the earth at the time of a thunderstorm, and the great amount of electricity disposed on the clouds themselves, considered as simple insulated conductors, has led some intelligent inquirers in this department of science, to question the perfect analogy of a discharge of lightning with that of the Leyden jar. The objections however will, on mature reflection, be found in no way subversive of the general principles we have been endeavouring to establish (10). Thus, whether electricity be accumulated on a thick or thin stratum of insulating matter (37), the result is the same; it is merely the action on distant bodies, as measured by the common electrometer, which is affected by it.

Now the term *free* electricity, applies in this case, to the greater or less degree of influence of the opposed coatings on each other, in respect of other bodies. But in the case of the opposed planes of the clouds and earth, the whole charge is necessarily free electricity, or free charge, since there exist no other bodies upon which its influence can be exerted. In the same way the electricity of the jar, when the coatings, fig. 9 (22), are very near, is really all redundant electricity as regards the coatings, although latent or inappreciable in respect of other bodies. Hence the electrometer, with a moderate accumulation, appears but little affected. The only difference at the instant of discharge, as already observed (21), is in the position of the discharging circuit, which in the case of the clouds and sea, is directly in the interval of separation. Now as we always find induction an essential condition (11) in every case of electrical action, whatever be the distance between the opposed bodies, the thickness of the stratum of air is evidently of no importance whatever; more especially when we take into account the great extent of the surfaces opposed, which may possibly include many square miles.

Although these views of the nature of electrical action in thunderstorms, are based upon very strong evidence from facts, they are, nevertheless, not so completely verified as to be entirely without the region of hypothesis. They are however, perfectly valid and admissible, so long as they run parallel with the course of nature, and link into an intelligible sequence, the results of observation and experiment. This is, after all, the great practical end of theoretical reasoning. It may be impossible that we shall ever arrive at a perfect knowledge of the subtle operations, from whence the phenomena of electricity result. Therefore any theoretical view of them, as of many other questions in physical science, is but a sort of intellectual contrivance, for representing to the mind, the order and connexion subsisting between observed phenomena; and a theory is in this sense always sufficiently true, if it explain them, without being at variance with any known fact. As a safe guide therefore to further inquiries, and as an artificial means of obtaining great practical results, the hypothetical views we have had recourse to, may be considered quite safe, more especially when the facts they link together, are most completely verified, and would still remain the same, although further discoveries in this department of science should demand a more perfect theory.

SECTION II.

APPLICATION OF METALLIC CONDUCTORS TO THE DEFENCE OF BUILDINGS AND SHIPPING FROM LIGHTNING.

Laws of Disruptive discharges—Observed effects on Buildings and Shipping—Practical results of the preceding Inquiries—Nature and operation of Lightning Rods—Conducting power of various Metallic Substances—Laws of Electrical Conduction—Mechanical effects of the Disruptive Discharge—What quantity of Metal is requisite in the construction of a Lightning Rod—How far does its protecting power extend — Practical deductions — General construction of Lightning Rods—Applied to Buildings—Lightning Conductors for Ships—Chains and other temporary applications considered—Conductors for Ships under a fixed and permanent form.

Laws and Operation of Disruptive Discharge.

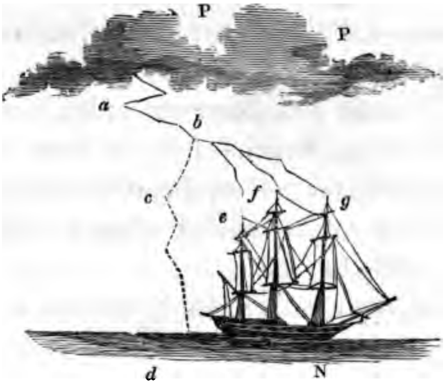
44. Whatever may be the theoretical views entertained relative to the immediate source of lightning, and the manner in which disruptive electrical discharges occur in nature, it will be well to bear in mind, that all such discharges, have nevertheless one common character,—all produce similar effects,—and are all governed by the same laws. We propose therefore, to consider these laws more particularly, with a view of arriving at certain practical deductions, immediately bearing on the question of the defence of buildings and shipping from lightning.

If we attentively examine the many recorded instances in which buildings and ships have been damaged by lightning, the course of the discharge may generally be traced; and this course is invariably determined through a given line or lines, which upon the whole, oppose the least resistance to the neutralization of the electrical forces. Both space and time are, as it were, economised in the restoration of the electrical equilibrium (2); for however small we assume the duration of the discharge to be, or however limited the distance through which it strikes, both these quantities would become still less, were other lines of transit provided of still less resistance. This is the leading phenomenon of all disruptive discharges; hence lightning seizes upon such bodies as lie convenient and ready for its purpose, absolutely avoiding other bodies, however near, from which it can receive no assistance. And it may be further observed, as a most wonderful and interesting fact, that at the instant before the explosion takes place, the stream of electricity, in the act of moving to restore the equilibrium of distribution, feels its way as it were in advance, and absolutely marks out the course it is about to take, an inductive action being impressed upon such bodies as happen to lie, in the line or lines of least resistance; this previous induction, by a sort of foresight, determines the course of the discharge. Its progress therefore, is not, as many imagine, left to the chances of the instant, to be, as it were, attracted or drawn aside by metallic bodies at any given point; on the contrary, the whole course of a stroke of lightning is already fixed and settled, before the discharge takes place.

45. The evidence deducible from observation as well as from physical investigation, is most conclusive on this point. It is quite clear, from what has been already shown (11), that any artificial elevation on the earth's surface, is in respect of a thunderstorm, a mere point in one of the terminating planes of a great electrical disturbance. The electrical forces cannot therefore be supposed, to operate exclusively between such an elevation and a charged cloud. A building or ship, is struck by lightning only in consequence of its being a point in one of the electrified surfaces; in

short, a heterogeneous mass, accidentally placed in a position to facilitate the neutralization of the electrical forces in a given direction, extending perhaps, over many square miles of cloud and opposed sea or land (35).

Fig. 15.



By way of illustration, let P N (fig. 15), represent the opposed terminating surfaces of the clouds and sea at the time of a thunderstorm, and N the position of a ship at the instant of discharge; let *a b* be the point, in which from any determining cause, the particles of the intervening air give way. Imagine further, that there were presented for the course of the discharge, such lines of transit, as *a b c d*, *a b e* N, *a b f* N, *a b g* N; then the question, whether the ship N would be struck by lightning, would depend on the respective resistances, in the direction of these lines; it might so happen, that the resistance in the direction *a b c d*, although very near the vessel might, from a variety of causes, be so much less than in any one of the other lines, that the discharge would not touch the ship at all. Conversely, the resistance might be *greater* in the direction *a b c d* than in any other, in which case the discharge would become determined through the ship, and one, two, or three, of the masts, would be struck by a division of the spark, in the way already stated (24), according to the equality or difference of the resistance in these directions.

46. We must not, however, proceed too hastily without verifying principles by an appeal to experience: for however perfect theoretical views of such questions may be, it is still always desirable to adhere carefully to facts.

Her Majesty's cutter *Hawk*, was struck by lightning in Broadhaven Roads on the 21st of January, 1840, and seriously damaged. About the same time, the electrical discharge fell so near the *Neptune*, a small revenue cruiser at anchor in Ely Bay, as to cause the vessel to fairly reel by the concussion*. Her Majesty's ship *Southampton*, of fifty guns, experienced a heavy storm of lightning and thunder on the 30th of June, 1842, on the coast of South America, when a heavy electrical discharge fell so close to the ship, that it appeared to strike the main-chains†.

During the passage of Her Majesty's ship *Vanguard*, of eighty guns, from Portsmouth to the Mediterranean, in 1840, a dense explosion of lightning fell close upon the ship's quarter, without affecting the masts[*].

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* *Mayo Constitution.*

† Master's log.

The *Dart* steam-packet, whilst on her passage from London to Margate, in July, 1829, was exposed to a severe thunderstorm, about five miles below the Nore. The electrical discharge struck the sea so near the vessel as to shake her considerably. One of the passengers stated that he saw a ball of fire fall into the water about twenty feet from the larboard side of the ship[†].

47. A great number of instances of this kind might be adduced in support of this important fact, it is however unnecessary to go at present into any further detail. We will therefore pass on to the track of the discharge, supposing it to be determined in the direction of the masts; and with a view of simplifying the question, we will select a common case in which it falls on one mast only, viz., on the main-mast, in the direction *a b f* N (fig. 15). In pursuing this course, the same general principle is apparent, *i. e.*, the electrical discharge is observed to fall on all those bodies which tend to assist its progress, and which happen to occupy certain relative positions, *and upon no others;* attacking with destructive violence, imperfect conducting matter, and producing in various insulators, intermediate between good conductors, all the effects of a powerful expansive force. If we examine the course of any discharge

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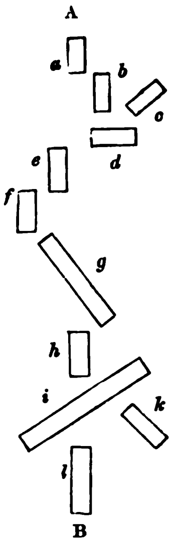
[*] *Extract from private letter.*

[†] *Report of Commission on Shipwreck by Lightning*, p. 84.

of lightning, through a building or a ship, we shall find this effect invariable. The damage has always ensued where good conductors cease to be continued, and the destructive effects most apparent, are those commonly caused by an expansive force.

48. Before we proceed, however, to trace these effects in the operation of lightning, it may not be unimportant to call attention to the following experimental results, as being particularly illustrative of the laws of electrical discharge.

Fig. 16.



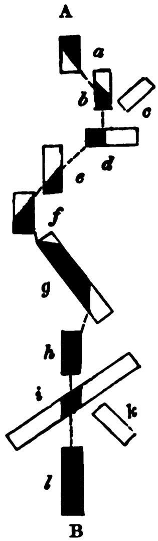


Fig. 17.

Let some small detached pieces of leaf gold, *a b c d*, &c. (fig. 16), be laid on a piece of paper in any casual way, and let a disruptive discharge find its way over these detached conductors, from their commencement at A to their termination at B. If the discharge be sufficient to burn up the gold and blacken the paper, its course will be very completely shown; it will be in the dotted line *a b d* and *e* (fig. 17), as copied from the result of an actual experiment. It is here especially worthy of remark, that not only are the pieces *c* and *k* untouched, being from their relative positions of no use in facilitating the progress of the shock, but even portions of other pieces are left perfect from the same cause; thus the transverse piece *i* is blackened only in its central part, and portions of *a b d e f*, &c., remain perfect; so little tendency is there in the discharge to affect any substance not essential to its progress, even up to the point of destruction of the conducting line.

49. If small particles of imperfect conducting matter, such as fragments of wafers, be placed in the intervals between the pieces of gold (fig. 16), those in the course *a b d*, &c, will be dispersed in all directions, whilst those out of that line will be undisturbed; and this is true, whether the thickness of the gold, be sufficient to transmit the discharge without dispersion of its parts, or not. Now these separated pieces of leaf gold, may be taken to represent detached conductors fortuitously placed in the construction of a building, or in the masts and hull of a ship; and the general result, in determining the course of the discharge of lightning, will be found precisely similar.

Observed Effects on Buildings and Ships.

50. The damage done by lightning to Her Majesty's ship *Rodney*, of ninety guns, may be adduced in illustration of this result in nature. This vessel, one of the finest of our line-of-battle ships in the Mediterranean, was struck by lightning on the 6th of December, 1838, off the south-east coast of Sicily, at 9 A.M. The electrical discharge fell on the vane spindle, which was of wood, and on the truck at the mast-head, as at *a* (fig. 18)*. It then glanced over the royal pole to the head of the top-gallant-mast at *b*, probably assisted by the moisture on its surface (30); here it fell on a copper funnel, sixteen inches long and ten inches in diameter, placed on the mast for the support of the rigging. The resistance from *b c* through the air, over the surface of the mast, seems to have been greater than through the wood: hence the top-gallant-mast, from *b* to *c*, was shivered; it now seized upon the metals about the head of the top-mast at *c*, and also on some men there on the cross-trees. From thence it struck over the surface of the top-mast to the metallic bodies about the parrel of the topsail-yard at *d*, and so passed *per saltum* to the lower cap at *e* and the lower-mast *m;* it entered the lower mast, and left it in a tottering state. The expansive effect was so great, that thirteen of the iron hoops were burst open: about seven feet above the deck, the concentrated shock divided; one portion

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* See Plate 2.

passed at once in the direction *s n*, over the hammock nettings into the sea; a second seized upon a metallic pump used for washing decks, and passed along the course of it through the ship's side, in the direction *s t o;* a third division passed below to the orlop deck, and through the metallic bodies in the hull at *p*, leaving the ship between decks full of a sulphurous odour and an apparent smoke. In this course, indicated by the waving dotted line *a b c d*, &c., the discharge evidently sought assistance from all the conducting matter it could find, viz., wet ropes, copper funnel for rigging, iron work, &c., about the topmast cap, men on the cross-trees, metallic bodies about the parrel of the topsail yard, &c.; and between all these it produced destructive effects. The interrupted circuit is quite evident in this case. It is traceable, first to the copper funnel at *b;* secondly, from thence to the conducting bodies at the heel of the top-gallant-mast at *c;* thirdly, from thence to the metallic masses about the yard at *d;* fourthly, between this and the head of the lower mast at *e;* fifthly, from this point over the iron hoops on the lower mast; lastly, to the hull and sea. The circumstance of the discharge striking over some portions of the mast without damage, is quite in accordance with all the known laws of electrical action already described (30); thus a trace of water will allow a highly-charged jar to explode over a slip of glass without damage; and Dr. Franklin found he could not destroy a wet rat by artificial electricity, although he could a dry one, in consequence of the moisture conducting the charge over the surface of the body.

51. The following cases of damage by lightning, which have recently occurred in the metropolis, are worthy of attentive consideration, inasmuch as the facts are still present to us, and the evidence they furnish of the course of electrical discharges is very complete. They have therefore been somewhat minutely described.

St. Martin's Church, struck by Lightning, 28th July, 1842.

Before tracing the course of the electrical discharge through the tower of this beautiful building, it will be requisite briefly to notice the position of the various rooms and substances through which it passed, together with such other circumstances as bear immediately on the great points under consideration.

A section of the tower is given in fig. 19*. The spire, S C A, terminates in an iron rod, C A, formed into a spindle at its extreme point, for the support of the vane, A. This rod is from four inches and a half to five inches squaer, and about twenty-seven feet in length. It projects about twelve feet into the air, and passes fifteen feet into the spire through a gilded ball of copper, thirty-three inches in diameter, and one-sixteenth of an inch thick, and through two solid blocks of stone, as represented in fig. 20. It is supported within by a strong cross of iron, *k* (fig. 21), let into the masonry at *c* (figs. 19 and 20). The weight of the bar is about twelve cwt. and three-quarters, and its extreme point about two hundred feet from the ground. There are other iron crosses in the interior of the spire, besides that supporting the spindle of the vane, as at *t* and *v* (fig. 19): these serve as cramps to the masonry; they are not connected with each other. The vane at A is constructed of sheet copper, well gilded, and is about eight feet long and six feet wide.

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* See Frontispiece.

The spire is a light hollow structure, forty-four feet high, standing on an open cupola, and surrounded by ornamental columns and arches*. The floor of this cupola is covered with lead, and there is a massive frame-work of wood and iron, resting on it. This frame is constructed in two parts, for the support of a flag-staff, F, one of which can be pushed out clear of the tower when required. Beneath the cupola is the dial-room, *f*, containing the iron spindles of the clock-faces, as at *e f n*. The figures marking the hours constitute portions of the stone facing which surrounds the recesses of the circles forming the centre of the dials, as represented at *d d* (fig. 22): these circles are formed of shutters of wood and iron, in eight divisions, and are painted black. The four cross rods at *e f* (fig. 19), carry the hour and minute hands of each dial, and are supported in the middle of the dial-room *f*, without touching the walls.

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* See fig. 22, Plate 2.

Under the dial-room is the belfry B, in which are the bells, suspended in frames in the usual way; they weigh from five to thirty-one cwt. Beneath the belfry is the clock-room G; the clock in this room is supported in a massive iron frame fixed to the floor; an iron rod *f* G, about three-fourths of an inch in diameter, and forty-six feet long, passes from the wheel-work up through the belfry B to the spindles at *f*, by which the requisite motion is conveyed to the hands on the dial-plates; this rod is constructed of several pieces, united by brass screws: it is cased in wood, and passes within ten inches of the lip of each bell.

Beneath the clock-room is the ringing-chamber R, having windows W W′ with iron frames; immediately without these is the lead, covering the roof of the church, as at M.

We have now before us almost every particular requisite to a clear comprehension of the track, and phenomena of the electrical explosion which fell on this fine structure.

The first point struck was the point of the vane-spindle at A; the discharge passed into the spire through the rod A *c*, without any damage to the blocks of stone immediately surrounding it, and without affecting the copper ball or the gilding of the vane. The only effect produced was the disturbance of a little cement about the ball, which seemed as if shaken by a violent concussion of the air. At the cross *c* the discharge left the vane-rod, and passed into the masonry of the spire, starting an angle stone as at *n* (fig. 21), and from thence so damaged the spire in passing down it, as to leave the whole in a tottering state. Two blocks of stone were thrown completely out of their places, and fell through the roof into the church, the joints of the spire were all loosened, and its general surface contorted. Two other stones were quite dislocated; if these had also been thrown out, the whole of the upper portion of the spire must have fallen. From the base of the spire, the discharge fell with destructive violence upon the frame-work of the flagstaff at *d*, the wood-work of which was shivered, and then seizing the lead floor of the cupola, it forced a passage to a metal clamp within the masonry, where it tore up and fractured a large flat stone, and turned it completely over; in this way it passed to the nearest points outside the tower leading to the north and west dials: upon these the discharge divided (as in fig. 22), and fell upon the gilded letters XI. and XII., the gold of which, on the west dial more especially, was burnt up and blackened. From these points it exploded upon the minute-hands; here it also blackened the gold, and damaged the points of the hands. From this, it passed along the spindles of the north and west dials into the dial-room, without affecting the surrounding parts, and seizing the iron rod *f* G, connecting the spindles with the clock, it passed safely within its case of wood, and between the masses of metal in the bells down to the works of the clock: the only traces left in this course, were a little fusion of the brass screws, and of the iron at the union of the joints. The discharge, on reaching the works of the clock, melted a small copper wire by which the lever handle key was suspended on the iron frame: it now spread over the wheels and other parts, magnetized the steel pivots, blackened the silver face of the regulator, and burst open the door of the outer wooden casing,—it did not, however, stop the clock. The discharge, on leaving these conductors, forced a passage through the floor of the clock-room G by the assistance of some metal clamps, into the ringing chamber R, leaving the floor as if blown up by gunpowder. Coming out just over one of the iron window-frames W, it shattered all the glass in the window by the violent concussion, and left marks of fusion on small streaks of lead in the joints of the stones. By this course, it reached the lead of the roof at M, and slightly fused it at the point on which the discharge first fell. After this it became dispersed upon the earth without further damage, by the large masses of metal and pipes connecting the roof with the ground.

52. It is impossible to conceive a case giving a better insight into the nature of disruptive discharges, through a fortuitous arrangement of good and imperfect conductors, than this now before us. In the first place, we may observe that all the damage has occurred in points where good conducting matter ceases to be continued,—as for example, between the termination of the vane-rod at *c* and the clock-faces at *e* and *f*, and again be-

tween the works of the clock at G and the lead of the roof at M, whilst the course of the discharge in the irregular line A*csdef*BGWM, is so marked and definite, and so independant of bodies not contributing to assist its progress, that we perceive it actually passing down the small iron rod *f*G within a few inches of the bells, without affecting in any way these large metallic masses, or disturbing the wooden case by which the rod was surrounded. The discharge, in passing upon the dials, selected the north and west faces as affording the easiest line of transit, and as the minute hands only, could contribute to the conduction, being at the time in a position to transmit it to the centre of the dial *d* (fig. 22), these only were affected; the hour hands, although in continuation with the lower part of the dials, were evidently without the line of action: the course of the discharge therefore, became diverted at right angles nearly from the line of the hands in order to pass upon the line of metals within the tower, thus completely coinciding with the phenomena of artificial discharge exemplified in fig. 17 (48)*.

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* Every care has been taken to verify the facts of this case. Mr. Watkins, optician, Charing Cross, London, well known as a careful observer of such phenomena, made a personal observation of the spire soon after the lightning fell on it, and very kindly furnished the result of his inquiries. Mr. R. Dyer, of the Norfolk hotel, Surrey-street, also devoted much attention to the subject, and obtained from those immediately connected with the church every particular that could be desired. Mr. Newberry, the steeple-keeper, Mr. Hennings, the builder, and Mr. Langstaffe,

Brixton Church, struck by Lightning, 24th April, 1842.

53. The course of this discharge is traced in fig. 23*, which represents a section of the tower. There is a metallic cross V on the summit of the dome; this cross is of sheet copper, four and a-half feet in height, and five inches square, and is supported by an iron bar, which passes within the cross through the masonry of the dome, and is secured by a nut at N. The masonry of the dome is very massive, and the joints of the stonework are strengthened by lead solderings. The dome is supported by stone columns about twelve feet high, as at M. Immediately under the cupola is the clock-room C, the roof of which is of wood covered with lead; C is the position of the clock: the works communicate with the dial-plates by means of iron rods, as D C half an inch in diameter. D is the position of one of the four clock-faces; the dial-plates are of sheet copper, about four feet in diameter, and the figures for the hours, &c., are covered with leaf gold. The works of the clock communicate with two bells at B by a small iron wire about thirty feet long, and one-tenth of an inch in diameter; this wire is not continuous, but made up of several pieces looped together; it is supported by means of small staples against an upright of wood. The bells at B are very

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who regilt the vane, &c., gave freely all the information in their power. T. Morris, Esq. architect, also contributed much valuable information.

* See Plate 2.

close to each other: they are quite clear of the walls and the floor, and the larger one is always in connexion with the clock by the wire *f i*,—in fact, the striking weight rests on it, being raised by the wire to strike the hour. Beneath the belfry B is a room E communicating with it by a trap; there is an iron clamp, *i*, under the floor, about fifteen inches from the bell, and immediately outside, at about a foot distant, is the base of one of the ornamental columns T, which surround the middle portion of the tower. There are sixteen of these columns, and they are about eighteen feet long. At the base of column T is the lead-work M descending over the roof, and connected with the earth by metallic gutters and pipes. On reviewing the position of these different parts, we cannot but be struck with the analogy in their electrical relation to similar parts in St. Martin's spire, just described; we should accordingly expect to find precisely similar effects, and such is really the case, the course of the discharge being as follows.

The explosion fell first on the cross V, and followed it down to the masonry of the dome; there it diverged, and rent the dome completely open, then finding its way along the inner side of one of the columns M, it slightly damaged the stone-work in the vicinity. It now reached the metals on the dials, and passed to the works of the clock at C by the iron rods D C, and from thence along the wire and wooden upright *f i* to the bell B; this wire was knocked to pieces, and portions of it dissipated.

From the termination of the wire it burst upon the floor and clamp at *i*, as the shortest and easiest course to the lead M on the roof of the church. Exploding upon this point, it produced, by a common law of electrical action, so much expansion as to shatter the base of the column T; the wood of the floor also at the clamp *i* was torn up, as in St. Martin's spire, but with less damage; after this the discharge found its way to the earth, with but little further difficulty. The interrupted circuit traceable here, is represented by the irregular line V *u* M D C *f i* T, &c., and the disruptive discharge is precisely of the same character and description as that just described (52)*.

54. In every instance of damage to buildings or shipping by lightning, the course of the electrical discharge is determined in a similar way, through points presenting the least resistance to its progress, and the mischief invariably occurs between detached

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* The facts connected with this case have been minutely detailed by Mr. C. V. Walker, and there is not the slightest doubt of their accuracy. It is, however, proper to observe, that in the account given by Mr. Walker, he supposes a great portion of the charge to have passed *outside* the building by an iron pipe, because the damage done at the point *i* was not, he thinks, adequate to the force of the shock as experienced at the base of the column T. This supposition, however, is not warranted by any trace of the discharge in the direction Mr. Walker has pointed out, and must, therefore, be so far regarded as hypothetical. His account of this case, however, is singularly clear and instructive.

masses of metal. The beautiful steeple of St. Bride's Church in London, struck by lightning in June, 1764, furnishes a most remarkable instance of this. The spire of this steeple, where it rises above the belfry, is composed of four stories of different orders of architecture, beside the obelisk immediately over them. The stone piers of these stories are connected together and strengthened by horizontal iron bars; near the height of the capital of the pilasters, each story has a set of four bars, placed crosswise, and tied together by chain bars within the stone work. The obelisk terminates in seven courses of stone, the five upper ones being connected together at the top and bottom by iron collars soldered with lead. An iron bar, about twenty feet in length and two inches square, passes through these for about ten feet in a groove cut through the middle of the solid stones, and filled in with lead. This bar rests in the two solid stones of the lower courses, in which it is sunk five inches deep, and is further secured by melted lead. The upper part of the bar is cylindrical, and covered for about ten feet by a ball and cross, and by a vane, all of gilded copper. To lessen the quantity of stone in this beautiful structure, cramps of iron are employed in several places, on which ornamental stones are placed. Other iron bars are also employed to support the top of the windows, so that a more complete series of discontinuous metallic bodies intermixed with imperfect conducting matter, cannot well be conceived. The experiments described

(48, fig. 17), very completely illustrate such a distribution.

When the lightning struck this steeple, it made successive leaps between these metallic bodies, rending and tearing up the masonry at the points where it entered and again left them; so that it was requisite to rebuild eighty-five feet of the spire. One of the iron bars in the composite story was found broken in two, and another bent to an angle of nearly forty-five degrees. No damage whatever, was done to the iron spindle, the vane or cross, or to the solid stones through which the iron bar passed. The gilding on the top of the cross, at the place where the discharge first struck, was the only part affected; this was either dissipated or discoloured: a little solder also was melted at this spot, which appeared as if acted on by fire. The lightning, it is clear, entered here upon the whole metallic mass, and was quietly conducted to the termination of the iron spindle in the two lower courses of stone: its destructive operation now commenced, and the destruction was repeated at each successive leap between the disconnected metallic substances employed in the construction of the spire. The last trace of it was at the west window of the belfry, from whence it appears to have found an adequate conduction to the earth*.

55. Before concluding these notices, it may not be unimportant to detail briefly, two cases of

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* *Phil. Tran.* for 1764, pp. 201 and 227.

damage by lightning which exhibit in a remarkable way its destructive effects at sea and on shore, and show still further, the absolute necessity of guarding against them.

Fig. 24, or vignette, represents the condition of the *Thisbe*, an English frigate, struck by lightning in January, 1786, near the Scilly isles, during her passage from Lisbon to England. The weather at the time was tempestuous and squally, with showers of hail, so that the ship was hove-to under storm stay-sails*. The electrical discharge, after disabling several of the crew, struck on the mainmast, and set the sails and rigging on fire: it also struck the foremast and shivered it†. To get clear of the burning mass, the master cut one of the lanyards of the main shrouds to windward, when the force of the gale carried the whole over the side, together with the mizen-topmast; the fore-topmast soon followed, so that the ship was left almost a total wreck. The electrical discharge knocked down several of the crew near the guns, and swept the decks‡.

Fig. 25 is an exact representation of the spire of St. Michael's Church, at Black Rock, near Cork, as it appeared on the morning of the 30th of January, 1836, after being damaged by lightning on the previous night. This steeple, or spire, was an elegant structure, built of limestone, and strengthened by iron cramps and bars in the usual way within and without.

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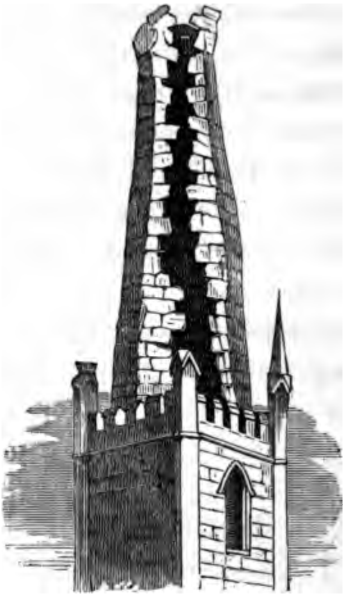
* Ship's log. † Idem.

‡ A similar result ensued in the *Lowestoffe*, a sister ship, in the Mediterranean, in 1796. This frigate was also dismasted, and left a mere wreck.

Fig 25.



The weather at the time was gloomy and wet the wind west, and very violent; the atmosphere was so obscured by the clouds, as to cause a terrific darkness.

The following is the account given by an eyewitness of the occurrence:—"A volume of transcendently white light burst upon us; it illumined the whole space around, and appeared immediately over our heads; at the same instant a sharp tremulous spark ran down the steeple of the church.

This was accompanied by an astounding noise, vastly greater than that of artillery. Imagination cannot form a picture of more awful ruin. The top of the spire was swept away; the remnant twisted in various places; the square steeple rent, and the stones scattered in all directions*."

The damage done in this case is, as perceived by the drawing, in a straight line, and is on one side only of the steeple: this was on the windward side, which probably received the greatest quantity of rain, and so rendered it the least resisting line, but not of sufficient conductibility to carry off the discharge without damage.

It is almost superfluous to observe, that these two cases completely accord with those previously related.

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[*] Extract from a letter, accompanying a lithographic sketch of the appearance of St. Michael's church on the morning after the storm. This church was built in 1827.

PRACTICAL RESULT OF THE PRECEDING INQUIRIES.

Nature of Lightning Rods.

56. THE damage sustained by buildings and ships in thunderstorms being invariably found to occur in the spaces where good conductors of electricity cease to be continued, it became an important question in practical science, how far it would be desirable to provide at once a continuous line of conduction, through which the electrical discharge might be transmitted without any intermediate explosion, and consequently without damage to the general mass. An idea first suggested by the American philosopher, Franklin, and since carried effectually into practice under the form of a lightning rod.

57. The application of such a rod to a building or ship, is evidently equivalent to the uniting into a continuous conducting train, all the detached metallic masses between which damage ensues, and in the case of particular buildings, into the construction of which such masses do not enter, it supplies the degree of conducting power requisite for their safety. A conducting rod, therefore, in whatever way it may be applied, is to be considered merely as a means of perfecting the conducting power of the whole mass, so as to admit of intense discharges of lightning being securely transmitted, which otherwise would not pass without intermediate explosion and damage; for it must never be forgotten, as an important

feature in the consideration of this question, that the materials of which buildings and ships are composed, are for the most part such as come under the denomination of conductors (7); the whole fabric is, therefore, to a greater or less extent, an electrical conductor. Now the chance of its escaping damage from a discharge of lightning, increases with its power of transmitting the electrical action by which it is assailed. If we could suppose a ship or building to have a perfect conducting power in all its parts, or if we imagine it to be metallic throughout, then damage from lightning would be unknown. Thus discharges of lightning struck repeatedly on the iron steam-boat which accompanied Lander in his last attempt to explore the interior of Africa, without producing the slightest effect on it; whilst vessels built of wood and metal were damaged. A man in armour would certainly be safe in a thunder-storm, from the great conducting power of the metal as compared with the human body. The great object therefore to be attained in the application of lightning conductors to the defence of buildings and shipping from lightning, is to bring the general mass as nearly into this state as possible.

58. It has been already observed (6), that Mr. Cavendish determined the conducting power of iron to be, in relation to that of water, as four hundred millions to one. Taking therefore the conducting power of water as unity, and assuming it as the value of the mean conducting power of the general mass of a building, which is upon the whole not far

from the truth, then, by giving a building a lightning conductor of great capacity, and connecting it with the detached masses of metal as far as is possible, we multiply its chance of escaping damage, in the intermediate points in which the conductor is applied, four hundred millions of times; and considering that by the laws of electrical action above determined (45, 48, 50), the electrical discharge finds its way through any line or lines, which upon the whole offer the least resistance to its passage, nothing can be clearer than the deduction, that any incapacity of the building as a whole, to transmit the charge through its parts without explosion, would be supplied by the presence of the conductor; and hence this multiplied chance of escape applies equally to the whole building. It is therefore demonstrable by physical facts, that perfect security is to be derived from an efficient conductor properly applied.

59. The first lightning conductor seen in England, was erected by Dr. Watson at Payneshill, in 1762. In 1769 the Jacob tower at Hamburgh was defended by a lightning rod, and after the cathedral church at Sienna had been repeatedly damaged by lightning, a similar means of protection was employed there also. The inhabitants at first regarded the rod with terror and apprehension, and called it a Heretic Rod; but on the 10th of April, 1777, a thunderstorm occurred, and there fell on the tower a heavy stroke of lightning, which was carried off by the rod, without doing the slightest damage even to the gilded ornaments near which it

passed*. The inhabitants now began to look on the heretic rod with more confidence; and it is an important fact, that this church does not seem to have suffered from lightning since.

Conditions requisite to perfect Security.

60. The general principles to be kept in view in the application of lightning rods, are these. The rod should be made of the best conducting substance; it should be continuous, and have great electrical capacity, and the metal of which it is composed should expose as great an extent of surface as possible, consistently with strength and durability. Its upper extremity which should project freely into the air; should be pointed; and may be triangular, somewhat similar to a bayonet. In cases where metallic vane-spindles or other points exist, it may commence from these. It should be led as directly as possible along the building, and be fixed to its walls. It should terminate immediately under the surface of the ground in two or more branches passing out in any convenient direction; these branches should, if circumstances permit, be connected with a spring of water, a drain, or some other conducting channel. It should be applied immediately to the part to be defended, and not at a short distance from it, and should be so applied, that a discharge of lightning falling on the general mass,

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* MARBUCH, *Enkyklopædie*, vol. i., p. 314.

could not possibly find its way to the ground by any circuit, of which the conductor did not form a part; that is to say, the conductor should be united with all the great masses of metal in its vicinity, which offer other possible lines of discharge: by this arrangement, no more of the discharge could pass in the direction of such masses, than could be transmitted without damage.

61. It is not difficult to carry out these views in the application of conductors to stationary elevations,—these may be defended by solid or tubular rods, or flat plates of metal, applied in any convenient way, and carried over projecting portions of the building: when fixed, such conductors require little further attention. In defending ships, however, the case is widely different, because the masts and rigging, the only parts to which they can be applied, are both subject to frequent change and derangement. The masts, although erect, consist of distinct portions; these it is often requisite to move one on the other, and sometimes to remove altogether. To construct and apply a conductor to a ship, such as may be permanently fixed, of great capacity, and require no handling or attention on the part of the crew, would seem at first a problem of no small difficulty.

Conducting Power of various Metallic Substances.

62. The lightning conductors first employed were usually of iron, and consisted of small rods or chains. Iron, however, is not the best metal for this purpose,

its conducting power being inferior to zinc, and far below that of copper. Dr. Priestley observes, that an electrical explosion which only melts a copper wire of a given diameter, would quite dissipate an iron wire of twice that diameter. "Copper," he says, "would therefore be a much greater security for a building than iron; but then it is more expensive." For certain small quantities of electricity, however, all the metals are equally efficient, or nearly so: it is in the transmission of intense charges that the differences become manifest. The conducting power of copper in such cases is full five times that of iron, and twelve times that of lead. Taking the conducting power of lead as unity, the following numbers accurately represent the relative value of the other metals, available for the purpose of lightning rods; the costly nature of gold, silver, and platinum of course excludes them from the list:—

Lead.	Tin.	Iron.	Zinc.	Copper.
1	2	2·4	4	12*.

Laws of Electrical Conduction.

63. The heating effect of the same, or different quantities of electricity, on metallic wires of the same or different diameters, is as the square of the passing quantity of electricity directly, and as the square of the diameter of the wire inversely. Thus the heat developed by a passing shock is four times as great when the quantity of electricity is doubled,

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* *Phil. Trans.* for 1827.

and only one-fourth as great when the diameter of the wire is doubled. A metallic rod, therefore, of twice the diameter, conducts twice the quantity of electricity with the same developement of heat. Taking the heat evolved as proportionate to the resistance, we may conclude, that the conducting power of a metallic body varies with the area exposed in cutting it transversely to its length; that is to say, with the area of its section, since this is proportionate to its solid contents.

64. In estimating the resistance of a metallic body to the transmission of a shock of electricity, we have also to take into consideration the distance traversed. Now the resistance to electrical transmission through a metallic wire, has been found to increase with the length of the wire; that is to say, the resistance to the transmission of the charge was twice as great when the length of the conductor was doubled*; a law observable from one hundred up to one thousand feet in length. A lightning conductor, therefore, should have its dimensions increased, when required to be of considerable extent.

65. The explanation of the above general laws seems to be this: supposing a given quantity of electricity to fall on a single metallic particle, and to experience a given resistance to its progress, then

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* These different results were determined by the author in various investigations, published so long since as the year 1825, and they have since been confirmed by other inquirers, both in this country and on the Continent.

this resistance would be diminished by placing a second particle by the side of it, for the charge would be divided between the two. If two other particles were added, we may conceive it to be still further reduced in proportion to the number of particles sharing in the conduction. Now, in the case of the section of a metallic wire, the diameter of which is double that of another, there are four times the number of particles,—hence the resistance with the same quantity of charge is reduced to one-fourth. In a similar way it may be shown, that by increasing the length of the conductor, we continually increase the number of particles to be passed through,—hence the resistance through twice the length will be twice as great, through three times the length three times as great, and so on. In the case of the quantity of electricity being increased, we have the resistance dependant not only on the increased charge, but also on its increased force. Thus a particle of metal conducting a double quantity of electricity is subject to a double force, since it is quite reasonable to conclude that the forces (12) with which the opposite electrical powers tend to unite, would increase with the amount of disturbance.

Mechanical Effects of the Electrical Discharge.

66. But it is not only the heating effect of the discharge we have to consider; it is necessary to take also into the account its more mechanical effects,—indeed, it is the expansive action which

produces the great mass of damage by lightning so commonly observed. If a powerful shock of electricity be transmitted by a fine wire, the wire will very often appear crippled throughout its length, and will exhibit a series of zig-zag creases. And if a similar shock be passed between two metallic balls in a confined portion of air, the air will be caused to expand with great violence, so as to frequently burst open the containing vessel. Light bodies such as wafers will become dispersed in all directions, when exposed to the expansive effect produced by the electric shock in passing through a short interval of air (48).

At the time the steeple of St. Bride's church, London, was struck by lightning, in June, 1764, it is stated by Mr. Delaval, F.R.S., who communicated a most interesting detail of the circumstances to the Royal Society, that "the lightning acted as an elastic fluid," and that "the effects are exactly similar to those which would have been produced by gunpowder, pent up in the same places and exploded. A stone weighing about seventy pounds was thrown to a distance of fifty yards; an iron bar half an inch in thickness, and about two feet in length, joining some of the masonry of the tower, was not only broken in two, but one part of it, according to Dr. Watson*, was actually bent to an angle of 45°" (53).

Mr. Delaval gives it as his opinion, that a very small rod of metal did not seem to be a sufficient canal to conduct so great a quantity of lightning as struck this steeple, and, upon the whole, thought that a conductor less than six or eight inches in breadth, and one-fourth of an inch in thickness (or an equal quantity of metal in any other form) could not be depended on in such cases.

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* *Phil. Trans.* for 1764.

In the shock of lightning which fell on His Majesty's ship *Elephant*, of seventy-four-guns, at Portsmouth, in November, 1790, all the iron hoops and wouldings on the main-mast were burst open and broken in pieces, and some of the parts scattered to great distances. Some of these hoops were half an inch thick, and five inches wide; the mast, although of immense size, being about three feet in diameter, and upwards of 110 feet in length, was entirely shook and shivered throughout*. Now, in these cases we do not find any melting of the iron work: we observe only the effects of a terrific mechanical power.

Another remarkably interesting instance of this effect was observed in the case of His Majesty's ship *Desirée*, already alluded to (35), struck by lightning in Port Antonio, in Jamaica, in the autumn of 1803. Admiral Ross, who then commanded the ship, states, that one part of the main top-mast was found on the following morning sticking in the mud on one side of the harbour, and another part in a timber yard on the opposite side.

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* *Naval Chronicle.*

In the application of lightning conductors to buildings, therefore, we have to consider the effect likely to be produced on them by the mechanical action of the shock, by which they may be disjointed, twisted, or rent asunder in various ways. Thus, the small conductor of linked brass rod, at Charles Church, Plymouth, struck by lightning in December, 1824, was literally torn in pieces and disjointed, and many of the links twisted into the shape of the letter S. A part of the small wire rope applied as a conductor to the Hotel des Invalides at Paris was broken into small pieces an inch or more in length, and scattered in all directions by the lightning which fell on that building in June, 1839. This conductor consisted of about twenty iron wires twisted together as a rope; the lead surrounding the lantern was torn up and scattered, but without any signs of fusion*.

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* *Comptes Rendus*, June 17, 1839.

A question of no small public interest arises here relative to the insurance of buildings against lightning, which has been assumed to be a *species of fire*, and that hence all buildings damaged by lightning are damaged as if by fire: but this is certainly not the case. A building may be struck by lightning, and may certainly be set on fire by it; but in the great variety of cases which occur, the damage is purely of a mechanical kind: thus, in the case of the spire of St. Martin's, already described, no damage could be said to have arisen from fire, and consequently no responsibility could attach to those who assured it against fire only; the damag was purely mechanical, and must be classified with the kind of damage occurring from a heavy gale of wind, or any other mechanical force.

67. The intensity of electrical accumulation having been found to decrease in an inverse ratio of the square of the opposed surfaces, some electricians were led to imagine that extent of surface was the great desideratum in the application of a lightning conductor. This decrease of intensity, however, does not affect the conditions of conduction as regards the heating effect of the discharge, for whether the quantity of electricity be accumulated on a large extent of surface, or on a small one, the heating effect, when the discharge does occur, is always the same. Whatever may be the distance at which the neutralization of the forces begins, they always unite with precisely the same degree of power, the quantity of electricity being the same.

This question, so frequently discussed, has not been fully appreciated in all its details, for although quantity of metal is an essential condition of a lightning rod, yet it is likewise desirable to place the metallic particles under as great an extent of surface as may be consistent with strength and durability, in order to keep down the intensity of the shock, and diminish the mechanical action. We may, in fact, for the moment, consider a conductor, while in the act of carrying off a charge of lightning, as an electrified body. Its electrical intensity, therefore, is very much less with a large surface than with a small one: hence, by extent of surface, we diminish the activity of the passing charge, and tranquillize its mechanical effect on the conductor. Thus we find, in a variety of cases of damage by lightning, that the passing charge, in striking on large expanded sheets of metal has become comparatively tranquil, and has been traced no further, whilst in striking on larger masses of metal, exposing but a small surface, it has assumed an intensely active state. The flash of lightning which struck His Majesty's ship *Badger*, lying in the Medway in August, 1822, vanished, after striking upon the copper lining of the galley, although just before, it had penetrated the mast, rent the copper, and melted the lead over the heads of two large bolts in the deck beams.

68. Although the general tendency of a discharge of lightning is always through the conductor, as being the line of least resistance (44), yet there may arise cases in which the electrical forces may be so circumstanced as to effect other lines of action near it, and in which damage may ensue. Thus, in the French frigate *Calypso*, fitted with a wire-conductor of small surface, two men in the main chains, who were standing in a slightly interrupted conducting communication between the wire and the sea, were struck senseless. A similar case is related by M. Arago, as having occurred in the French frigate *Junon*. In fact, wherever from any cause the resistance in the direction of the conductor is considerable, the chances of damage in some other direction become multiplied. Thus, a case occurred at Bayonne, in which the length of the conductor was unnecessarily increased,—that is to say, instead of terminating at once in the ground,

it was led off at the foot of the building on semi-insulating stakes of wood for some distance; the charge here divided upon other lines near the conductor, and caused damage*.

69. Provided the quantity of metal be present, the form under which we place it is evidently of no consequence to its conducting power, since it would absurd to suppose that a mass of metal, under any form, did not conduct electricity in all its particles,—indeed, we know that it does so, and that it is impossible to fuse by electricity *a portion only* of a homogeneous metallic plate of uniform thickness. Again, if the heating effect of a given quantity of electricity on a metallic wire be measured, and then the wire be rolled out into a flat surface, or otherwise drawn out and placed under the form of two or more smaller ones, still the same heat will be evolved when conducting the same charge†; there is consequently no disadvantage in giving a lightning rod as much superficial capacity as possible as regards conducting power, whilst, on the contrary, the diminished intensity attendant on it is very advantageous: this effect of superficial conductors appears to depend on the removal of the electrical particles further out of the sphere of each other's influence. In a dense solid rod they may be supposed to be in a state of compression, in each other's way, as it were,—

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* *Annuaire* pour 1838, p. 597.

† *Trans. Royal Society* for 1827.

whereas, by expanding the same quantity of metal into a larger surface, we immediately free them from this condition, and allow them greater space*.

In order, therefore, to resist the heating effect, we require quantity of metal; to restrain the electrical intensity, and to diminish the mechanical force, we require extent of surface. The distinction is nice, but it is a very important one.

70. Two questions here present themselves which demand attentive consideration, viz., what quantity of metal is requisite to perfect security, and to what extent will a lightning rod afford protection,—in other words, what is the sphere of its influence? These problems, although apparently difficult, admit of a satisfactory solution—a solution, it is true, depending on the results of experience, but still perfectly conclusive; for it is here to be remembered, that we seek protection not against discharges of lightning which have no existence out of the imagination, but against such as have fallen within the experience of mankind—not against convulsions of nature, in which it would probably be of little consequence whether we had lightning rods or not, but against probable and tangible results of the operation of a given natural agency, with the laws of which we are not ill acquainted. Now, we have the recorded experience of more than a century to guide us in this inquiry; and first, with respect

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* See *Phil. Trans.* for 1834 and 1836, pp. 232 and 450, for some further inquiries on this point by the author.

to the actual quantity of electricity which may be contained in a flash of lightning, and the quantity of metal requisite to resist its effects.

What quantity of Metal is requisite for a Lightning Rod?

71. Perhaps one of the most terrific discharges of lightning ever experienced, was that in the case of the New York packet, struck by lightning in the Gulf Stream, in April, 1827, already noticed (34). In this case the discharge fell on a pointed iron rod four feet long, and half an inch in diameter; some few inches only of the rod near its point were melted; the linked iron chain which descended from this rod to the water, about a quarter of an inch in diameter, was knocked in pieces by the expansive force of the shock, and some of the links fused. The flash of lightning not only melted some of the links, but "caused them to burn like a taper." "The melted iron fell in glowing drops upon the deck, which was instantly set on fire wherever the burning matter fell." "Such was the violence of the shock, that the ship recoiled, or, in sea phrase, lurched so strongly, as to throw down the people on the deck*." The results of a great natural experiment are here presented to us, and we see that an iron rod of half an inch in diameter effectually resisted a flash which fused and destroyed a chain of about one half of its dimensions.

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* *Report of Commission on Shipwreck by Lightning.*

The flash of lightning which struck Her Majesty's ship *Rodney*, in December, 1838, was so powerful that it quite dispersed the top-gallant mast in small chips, covering the sea with splinters, set fire to the main-topsail, tore a piece ten feet long out of the topmast, burst thirteen hoops on the mainmast, each five inches wide and half an inch thick, and traversed the mast with destructive effect for fifty-three feet. Now this charge passed without fusion on the copper funnel, sixteen inches long, ten inches in diameter, and less than a quarter of an inch thick, belonging to the top-gallant rigging.

In September, 1833, two successive discharges of lightning fell on His Majesty's ship *Hyacinth*, in the Indian Ocean, and descended by the fore and mainmasts to the sea. The top-gallant and topmasts were literally shaken into a bundle of laths, so that they could scarcely be supported; the topmasts thus shivered were from eleven to twelve inches in diameter and about forty feet in length. This destructive shock was safely conducted away from the termination of the topmasts by a chain sheet fifty feet long, made of iron rod half an inch in diameter, and finally through the ship by a copper pipe, three inches in diameter, one-eleventh of an inch thick, and ten feet long*; before reaching these bodies, which were direct conductors to the sea, the discharge ravaged and destroyed the masts through a distance of nearly eighty feet; the chain did not show any marks of fusion.

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* *Report of Commission on Lightning Rods*, p. 44.

In the summer of the year 1760, a heavy discharge fell on a conductor fixed on a house in Philadelphia. This conductor consisted of an iron rod, half an inch in diameter; it extended nine feet above the chimneys, and terminated in an iron stake in the ground. The part above the chimneys was tipped with brass rod, about a quarter of an inch in diameter and ten inches long. Mr. West, the owner of the house, judging from the crash that the conductor had been struck, had it examined. About three inches of the brass rod were observed to have been fused, and some of the fused metal had sunk down about the remaining part of the rod, forming a rough irregular cap about it. The house was not damaged, nor were any further effects produced on the conductor*.

On the 26th of January, 1838, a flash of lightning fell on Her Majesty's ship *Dublin*, of fifty guns, at Rio de Janeiro. It was carried off by a conductor of long copper links, each link being about a quarter of an inch in diameter, and ten inches long. The conductor was "regularly melted" in several parts; these fell on the deck; other parts, which remained attached to the line supporting the chain along the rigging of the ship, appeared as if they had been exposed to a very fierce heat. This line was not hurt, nor was any damage done to the rigging†.

A house was struck by lightning at Tenterden, on the 17th of June, 1774. The discharge was conducted by an iron bar three-quarters of an inch square, but produced no effect on it*.

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* *Phil. Trans.*, vol. liii., part 1.

† *Report on Shipwreck by Lightning*, p. 94.

In June, 1772, a discharge of lightning fell on the Vicarage-house at Steeple Ashton, in Wiltshire. The iron bell-wires in both the parlours and in the hall were entirely dispersed, *except in their twisted or double portions*†.

In June, 1828, a heavy flash of lightning fell on the spire of Kingsbridge Church, in Devonshire, and was received on an iron spindle, seven feet long and one inch in diameter, without producing the least effect on it, or damaging the stones around it: but on leaving the spindle, however, it shattered the tower, and did considerable damage.

In the case of Charles Church at Plymouth (66), although the wire was knocked in pieces at the points of junction, and considerably bent, it was not materially damaged by fusion.

In August, 1822, a heavy discharge of lightning struck His Majesty's ship *Beagle*, in the Rio de la Plata, South America. The ship had conductors made of plates of copper, three-sixteenths of an inch thick, and varying from an inch to five inches in breadth: these were fixed in her masts. The masts terminated in a copper spindle for the vane, half an inch in diameter and two feet long, and beneath in the metals of hull and in the sea. Although the vessel trembled under the discharge, and the mast appeared to be enveloped in a blaze of fire, yet not the slightest effect was produced on the conductors, nor was any damage done to the vessel*.

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* *Phil. Trans.* for 1775.

† Ibid, for 1773.

In August, 1841, Her Majesty's ship *Actæon*, of twenty-six guns, similarly fitted with conductors in her masts, was struck by a violent discharge of lightning at midnight, off the central coast of America. The whole mast seemed to be in a blaze of light, and the ship, as in the former case, was shaken by the concussion. Some cutlasses stowed round the mast rattled in the stand, but no marks of fusion or other damage occurred either to the conductors or to the ship†.

72. In reviewing in this way a great variety of cases, in which buildings and ships have been exposed to appalling storms of lightning in various parts of the world, and throughout a century of years, we are enabled to appreciate the power of metallic bodies to carry off lightning with safety. Now we do not find in any of these cases that a conducting rod, or other mass of metal, equal in substance or conducting power, to a rod of copper half an inch in diameter and six inches long, has ever been fairly melted. On the contrary, heavy discharges have traversed rods of less dimensions with safety.

It was stated by Mr. Wilson, in the *Transactions*

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* *London and Edinburgh Journal of Science*, May, 1840, p. 40.

† *Nautical Mag.*, November, 1842.

of the Royal Society for 1773, vol. LXIII., that "parts of the conductors, consisting of iron, in the stone gallery of St. Paul's Cathedral, London, showed marks of having been made considerably hot, if not absolutely red, by a stroke of lightning which happened in March" of that year. Now these conductors consisted of iron bars, six inches wide and more than an inch in thickness. Mr. Wilson also states in the same paper, that in Martinique a flash of lightning occurred which reduced a bar of iron one inch in diameter to the "thickness of a slender wire only." Two men it appears were killed by this flash near a church wall, and the effect on the iron rod was observed on looking over the wall.

Although it is certainly not impossible for iron bars of considerable magnitude to become intensely heated by heavy discharges of lightning, yet it must be confessed that the evidence on which these statements rest is anything but conclusive. Neither of the iron bars was examined previously to the lightning which was supposed to have fallen on them, so that we cannot be certain that the appearances of heat which they exhibited were not the result of other causes. In the case of the bar in the churchyard at Martinique, it by no means follows that the wasting of the bar was the effect of lightning; it might have been the result of oxidation and time, especially as such appearances are by no means uncommon in bars of iron long exposed to the weather; besides, the effect itself, as a result of electrical discharge is highly improbable, for although chains and other conductors made up of detached pieces may be fused in some particular points, yet we have no case of a continuous rod or wire of metal destroyed or wasted in part by ordinary electrical action. We cannot, for example, by any contrivance, fuse the outer portion of a wire, and leave the heart of it as it were untouched; and in all instances in which iron shot or other metals have exhibited marks of fusion on their surface, it has been a sort of blistering of the immediate point on which the discharge first fell, and in which point it is well known the most intense action is produced.

The appearances on the conductors of St. Paul's may have been present from the time they were forged. Admitting the bars, however, to have been made red hot by a stroke of lightning, then have we the strongest possible evidence which can be adduced in favour of superficial conductors of copper; since the same charge must have passed through the ball and cross, consisting of *extremely thin copper sheet*, which is still to be seen at the Colosseum, London. But on this the discharge had no effect.

We may therefore feel quite assured, that a copper rod of three-fourths of an inch in diameter, or an equal quantity of copper under any other form, would withstand the heating effect of any discharge of lightning which has yet come within the experience of mankind.

73. This conclusion becomes the more evident,

when we take into account the way in which a lightning rod would most probably receive a charge of lightning, viz., on an acutely pointed extremity; by which a very considerable portion of the charge, if not the whole, would run off in an attenuated stream. This happened in the cases of the *Beagle* and *Actæon* above quoted. The observers, at the time of the discharge, heard a loud whiz or rushing noise, as if the safety-valve of a steam-boiler had been suddenly opened: now this is precisely what occurs when we endeavour to discharge an electrical jar by means of pointed conductors. The discharge is accompanied by a whizzing sound, and it is well known that we cannot fuse so great a length of metallic wire with a battery discharged in this way, as can be fused by means of a concentrated explosion.

It may not be out of place to remark here, that a somewhat absurd discussion arose in the year 1773, relative to this question of pointed conductors; Mr. Wilson and others contending, that the influence of points was prejudicial to the security of buildings, and that conductors should invariably have large rounded terminations. We shall eventually see, that the reasoning they employed, is contradicted by the whole course of experience, and after all, involves a sort of fallacy; since any termination which can be conveniently given to a conductor, even if it were a ball of a foot in diameter, would be, in relation to perhaps one thousand acres of cloud, virtually a pointed conductor.

The more mechanical or expansive effect of the discharge (66) may be avoided by giving the conductor as great an extent of surface as possible, and by perfecting its continuity. In most of the instances which we have quoted of damage to conductors by expansion, the discharge has broken upon them as it were *per saltum*, through an interrupted circuit. In others the conductors have been of very small superficial extent, or not perfectly continuous. Where due attention has been given to these conditions, the expansive force of a shock of lightning, received on a pointed conductor, may be taken to be extremely small. We have good evidence of this in the several discharges of lightning which have fallen on ships of Her Majesty's navy, having conductors of copper plates fixed in the masts. In no instance have these plates been disturbed, or have the powerful shocks to which they have been exposed, ever evinced a state of great intensity in passing down them.

How far does the protecting power of a Lightning Rod extend?

It is not easy to assign the limit of the protecting power of a conductor. The French philosophers consider it will afford protection over a circle equal to twice its radius*: this, although possible in certain cases, is by no means a general truth. All the experience we have of the operation of conductors on discharges of lightning, tends to the conclusion, that they have no influence whatever in determining the course of such discharges, further than arises out of the circumstance of their furnishing an easy line of conduction. That they do not always afford protection over any considerable distance, is clear from the following cases:—

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* *Annales de Chimie et de Physique*, vol. 26.

Her Majesty's ship *Endymion*, commanded by Captain the Honourable F. Grey, was struck by lightning at Calcutta, in March, 1842. This frigate had a chain conductor on the mainmast, applied in the usual way, not very dissimilar to that recommended in the report of M. Gay Lussac to the Royal Academy of Sciences at Paris. The electrical explosion, instead of falling on the conductor, struck the foremast, shivered the top-gallant and topmast, and damaged the lower mast. Now in this case the mast struck was not above fifty feet distant from the mainmast, which was furnished with a conductor, and had a radius of one hundred and fifty feet[*].

Her Majesty's ship *Ætna* was struck by several heavy electrical discharges at Corfu, in January, 1830. These for the most part passed down a chain conductor attached to the mainmast. One of the discharges, however, struck the ship near the bow, and exploded about twelve feet above the forecastle, close to the foremast, knocking down all the people on deck, and doing other damage[†].

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[*] Ship's log, and private letter.

[†] Ship's log.

The Board-house, at Purfleet, was struck by lightning on the 12th of May, 1777*, at a point upwards of forty feet from the conductor with which the house was furnished. The damage, it is true, was small; a few stones fastened by iron cramps not connected with the conductor were thrown down. The Board-house was a lofty building, with a pointed roof, well leaded, and connected by lead gutters and pipes with the earth, and with wells forty feet deep, for the purpose of conveying water forced up to a cistern in the roof. It was therefore only thought necessary to add an iron spike, about ten feet long, to the middle of the highest part of the roof. About one hundred and fifty yards from this building were five powder magazines, each one hundred and sixty feet long and fifty-two feet wide, having spiked conductors at each end, projecting ten feet above the roofs, and connected with wells of water It is quite apparent here, that so far as relates to the *influence* of a conductor over a given area, the experiment is conclusive, and the result shows that we cannot always calculate on the radius of protection; thus confirming the deductions already arrived at (46)†.

The Poor-house at Heckingham was struck by lightning on the 17th of June, 1781, which damaged one of the extreme corners of the building, situate seventy feet from the pointed conductors with which the house was furnished. Little or no damage, however, was sustained. The house consisted of a central range of buildings and two flanks. In general form, approaching that of the letter H. There were eight chimneys; each had a pointed conductor. The flash appears to have divided in this case before reaching the ground (24). One portion struck on one of the conductors, and was carried off; a second struck the extreme point of the building, and set it on fire; a third fell on the earth immediately in front of it*.

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* *Phil. Trans.* † Idem.

The house at Tenterden, already referred to (71), had two stacks of chimneys at each end. To one of these stacks was fixed a conductor of iron rod, projecting five feet above the chimney. Now, the discharge fell on one of the chimneys fifty feet distant, at the opposite end of the building; being the chimney diagonally opposite to that on which the conductor was placed, and in passing to the earth, it did considerable damage. The whole of this shock was finally concentrated on an iron bar three-quarters of an inch square, and produced no effect on it, as already noticed (71). The house was about thirty feet wide†.

75. Although these cases evidently throw doubt on any theoretical calculation as to the limit of distance, within which a pointed lightning conductor will afford protection, and confirm in a remarkable way the views we have taken of electrical discharges from the atmosphere (44); still they bear a small

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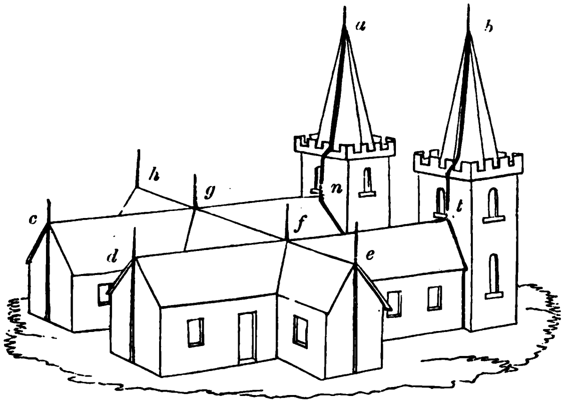
* *Phil. Trans.*, vol. LXXII., p. 377.

† Idem, 1775.

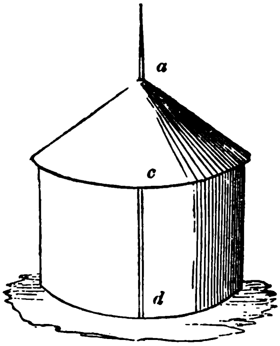
proportion to the great mass of instances, in which lightning falling on buildings has struck on the conductors attached to them, especially in such buildings as have any elevated parts, as the spires of churches, central cupolas and domes, columns, and the like. Even in ships, the exceptions are by no means numerous, although it is certainly very undesirable to trust to a conductor on one of the masts only. To meet, however, the great exposure of large ranges of straggling buildings, it evidently becomes requisite to distribute connected conducting lines through them in any convenient way, and to unite these lines with pointed conductors placed at given parts of them. Thus, in such a building as that represented in the annexed figure (26), pointed conductors should be applied from the points *a*, *b*, *c*, *d*, *e*, &c., and these conductors should be tied into one general whole by bands of metal, *c n*, *d t*, *e h*, &c.

Fig. 26.



The perfect defence of powder magazines from lightning by pointed conductors is to a certain extent difficult, from this particular cause,—that is to say, being frequently constructed in a series of long straggling buildings, they become more exposed to the chances of being struck on some point distant from the conductors. The safest form for a powder magazine would evidently be a circular building covered by a conical metallic roof, as represented in the annexed figure (fig. 27). In this case we should merely have to apply a rod to the vertex

Fig. 27.



at *a*, and lead other vertical rods, as *c*, *d*, to the earth. If the roof were not metallic throughout, then it would be necessary to lead three or four direct lines of metal over the ridges of the roof, or over the cone continuous through *c*, *d*, to the ground. A powder magazine made up of any number of such buildings might be considered as perfectly secure. Were these buildings constructed entirely of metal, as, for instance, of iron, or covered with metallic plates such as zinc,—then, without doubt, no possible damage could ensue, especially when defended by a point. If the object, in the construction of powder magazines, be to render them proof against missiles by means of solid arches, then such a mode of building could be as easily carried out under a conical roof, as under any other.

Practical Deductions.

76. From these inquiries, we arrive at the following deductions:—

1st. Copper is the best kind of metal for a conductor.

2nd. The quantity of metal should not be less than that represented by the section of a solid cylinder half an inch in diameter.

3rd. The metal should be placed under as great an extent of surface as is consistent with strength, and should be perfectly continuous.

4th. The conductor should involve in its course the principal detached masses of metal in the building.

5th. It should be placed as close as possible to the walls which are to be defended, and not at a distance from them, and be carried at once directly into the ground.

6th It should be attached to the most prominent points of the building, and if the length be very considerable, its dimensions should be increased.

Lastly. In extensive ranges of buildings, all the most prominent parts should have long pointed rods projecting freely into the air, and the greater the range of building, the higher they should be.

General Construction of Lightning Rods applied to Buildings.

77. A very efficient conductor for general purposes maybe constructed of copper pipe, varying from one to two inches in diameter, and about one-fifth of an inch thick. It may be prepared in lengths of about ten feet, and be united at the line of fixing by screwing the lengths together upon short intermediate pieces, as represented in the annexed figure (28), in which *a*, *d* represents an intermediate piece, and A, B, two lengths. These intermediate pieces may also be of thick tube, about two inches in length; they should have two projecting studs, *a*, *d*, and an intermediate thicker ring or shoulder against which the pieces A, B, should be screwed; thus in applying the whole conductor to the side of a tower or building, it may be supported by means of coupling-pieces or rings, M (fig. 29), attached to the masonry as in fig. 36.

Fig 28

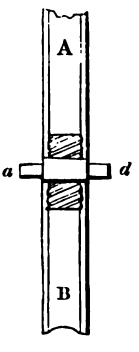
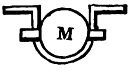


Fig. 29.



A conductor of this kind was applied to the clock-tower of the Royal Victualling-Yard at Plymouth, in the year 1834, and lately to the high chimneys there; also to some high towers in the West Indies and in Wales. They are very portable, and easily managed. Fig. 31 represents this conductor fixed to the masonry of a building, and Fig. 30 its pointed extremity; this is constructed of a solid copper rod, eighteen inches long, and about three-fourths of an inch in diameter: it is screwed into a solid plug fixed in the tubing. The lower extremity has three divergent branches, *a*, *b*, *c*, passing in different directions immediately under the surface of the ground, which should be connected, if possible, with any convenient conducting channel near them.

Fig 30.

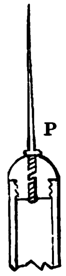
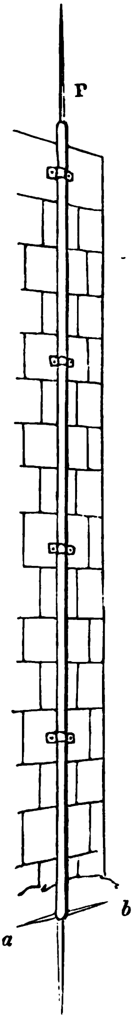


Fig. 31.



In ornamental buildings, such as columns, &c., where it is an object to avoid anything likely to interfere with the appearance of the structure, the conductor may if possible be carried down through the centre; in this case, however, it is requisite to fix it securely, and to perfect its continuity throughout. The monument erected at Edinburgh, principally by naval officers, to the memory of the late

Lord Melville, had by the direction of Sir David Milne, the Chairman of the Committee, a hollow way left in the centre of the stair from the bottom to the top of the column; from this a drain was dug fifty feet long into the adjoining ground. Nothing could be more judicious than this arrangement: and to make it still more complete, openings were left to examine the conductor when required. The conductor itself consisted of an iron chain connected with a copper bolt through the statue on the top; the chain traversed the hollow way in the stair, and proceeded to the ground; and had not some mischievous person on one occasion displaced the chain, by dragging it up from the ground, and leaving it suspended in a coil by means of a stick thrust through one of the links, this column would not have suffered as it did from the effects of lightning*. Hence it is important that in these cases the conductor should be a fixture continuous in the building, and forming, as it were, an integral portion of it.

When the conductor cannot be led through the centre of a column, it may be applied to its surface under the form of copper plates, varying from five to six inches in breadth, and one-fifth of an inch in thickness: these being fixed firmly to the masonry, may be covered with any sort of powdered stone, so as to assimilate its appearance with the building.

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* In September, 1838.

It is proposed to apply a conductor of this kind to the Nelson monument now erecting in Trafalgar-square, London. The plates of copper are three inches wide, and one-fifth of an inch thick, led in two lines along the adjacent fillets of the flutes of the column, and applied in lengths of ten feet united by dovetailing: by means of the new blow-pipe, the union may be made very perfect. The whole is pinned to the masonry by copper nails secured with lead: thus the shaft itself has a metallic conductor of considerable capacity. The conducting plates are united to the ornamental bronze work surrounding the capital, which is again connected with bands of metal, traversing the back and sword of the figure, and ending in two points, one at the aigrette of the hat, the other at the extremity of the sword. At the pedestal, the two separate lines of metal unite with a plate six inches wide, carried on near the north-east angle to the earth, where it is connected with three pointed branches under the surface of the ground, thus fulfilling the requisite conditions for a perfect defence (74).

The beautiful column termed the Monument, erected in commemoration of the great fire in London, has a most effectual conductor attached to it in the following way. The column is terminated by a metallic vase four or five feet in diameter, surrounded by pointed metallic plates representing flames of fire. Between this and the floor of the gallery are four thick bars of iron supporting a set of iron steps. One of these bars, an inch thick, and five inches wide, is connected with the iron rail of the staircase, which reaches to the bottom of the building*. The whole height of this structure, including the blazing urn at its summit, is 202 feet; it has never yet been damaged by lightning.

In particular cases in which expense must necessarily be considered, wrought iron tubing may be employed; it should not, however, be less than two inches in diameter, and three-tenths of an inch in thickness. The joints may be united as before†, and the conductor fixed to the masonry by couplings of cast iron. If solid rods be used, they should not be less than three-quarters of an inch in diameter.

78. Conductors for the protection of buildings are not unfrequently insulated in their course by means of glass, pitch, or some bad conductor, or otherwise are applied at short distances from the walls, so as to inteprose a stratum of air between them and the building. This practice is not only useless but disadvantageous, and is manifestly inconsistent with the principle on which conductors are applied, viz., that of providing a line of conduction to the earth, which, by a law of nature, the electrical discharge will follow in preference to any other. To imagine the possibility of its leaving such a line, to move in a more difficult path through the

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* *Phil. Trans.*, vol. LXIV., p. 389.

† Fig. 28.

building, is virtually to admit that we distrust the facts upon which our reasoning is founded. But an electrical discharge is never found to leave an easy line of transit, in order to pass upon matter out of such a line (44): the insulation of conducting rods is evidently unnecessary. If the conductor be placed at a short distance from the building, it is decidedly badly placed, since experience has shown (76), that discharges of lightning are often uncertain, and determined through the air in other directions than that of the conductor. Hence we cannot apply a conductor too closely to the walls of the building which we desire to defend. Besides, it may be observed, that if by any law of electrical action, the discharge could pass out of the line of the conductor, it is very unlikely to become arrested in such a course by a few inches of any solid insulating substance, or by a few feet of air. A flash of lightning which can break through a distance of several hundred yards, in an atmosphere of the ordinary density, and shiver the most compact bodies into fragments, would scarcely be arrested by such insignificant means in any course it may be determined in. The principle of a lightning rod is either absolutely true, and in accordance with certain laws of nature, or it is a mere assumption unsupported by such laws; but it cannot be both.

79. Whilst on this point, it may not be out of place to notice an opinion prevalent with many, viz., that by placing a ball of glass on the projecting points

of buildings and ships, lightning would not fall on them, glass being considered as a repeller of electricity. Under this impression, thick balls of glass have been in some instances placed on lighthouses and on ships' masts. The vane rod of Christ Church, at Doncaster, had a glass ball at one time fixed on it, until a discharge of lightning fell on the building, and demolished nearly half the spire, besides doing other damage. The application of glass in this way as a defence from lightning, is manifestly absurd, on the grounds above mentioned: the glass being merely a substance of low conducting power, and not dissimilar to the air in its electrical properties, it may in this sense be considered as a mass of air of unusual density.

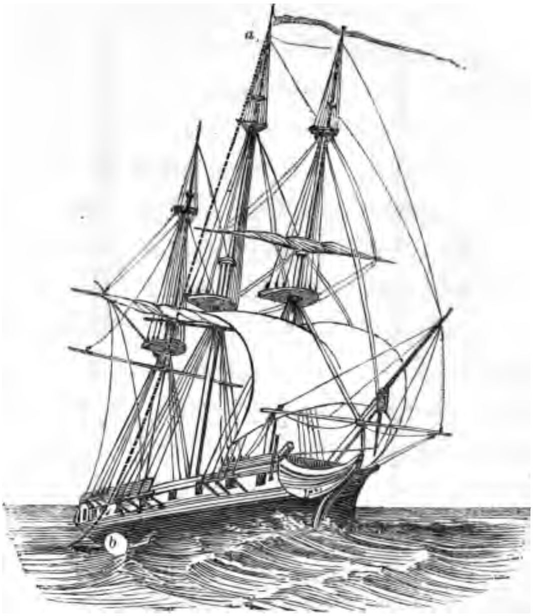
The employment of glass as a repeller of electricity being founded altogether upon an assumption, and totally at variance with the first principles of electrical science, it is not without regret we find it employed in some of our public buildings of great national importance, as, for example, in some of our lighthouses.

Lightning Conductors for Ships.

80. The lightning conductors first applied to ships, consisted of iron chains, or long links of small iron rod; these were joined by rings, in order to give flexibility to the whole line, and render it consistent with the nature of a ship's rigging. These chains were commonly attached to the head of the mast, and carried from thence

over the ship's side to the sea, as represented in the annexed figure 32, in which *a b* is the chain passing along the rigging, and supported by a small line (fig. 34) from the head of the mast at *a* to the sea

Fig. 32.



In the year 1762, Dr. Watson, a gentleman of considerable attainments in science, recommended, in a letter to Lord Anson, (then the first Lord of the Admiralty,) that His Majesty's navy should be supplied with lightning conductors, to be constructed of long links of copper rod, about one-fourth of an inch in diameter, united by small eyes turned in each extremity, as in fig. 33, the whole being attached to a hempen line (fig. 34), applied as just stated from the mast-head to the sea. One conductor of this kind was in consequence of this suggestion supplied to each of His Majesty's ships; it was packed in a box, and directed to be triced up by the signal halliards when occasion required.

Fig. 33.

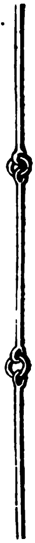
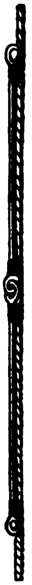


Fig. 34.



Such a conductor would without doubt go far in defending a vessel against a stroke of lightning, provided it was fairly in its place, and that the electrical discharge fell directly on the mast to which it was applied. A ship, however, being constantly exposed to heavy gales, and the masts and rigging always open to the operation of violent mechanical forces, renders the use of such chains not only difficult but extremely precarious. Hence they have fallen into disuse, and our shipping has remained exposed to the ravages of lightning; as is fully proved by the vast amount of damage so frequently occuring.

Beside these considerations, there is a manifest electrical disadvantage in the employment of linked or chain conductors. The expansive and heating effect of the electrical discharge, is in all the discontinuous points so powerful, that the link is often broken by it, and the metal not unfrequently fused. Such conductors are consequently very liable to be broken in pieces; as in the cases of the packet ship *New York* (71), Her Majesty's ship *Dublin* (71), the church at Plymouth (71), and several other instances. The discharges which fell on Her Majesty's ship *Ætna* (74), are said to have covered the line of rigging with sparks. This effect may be pleasingly illustrated by passing the shock of a battery over a small iron chain hung in a series of festoons. Brilliant sparks and scintillations of ignited iron will appear throughout its length. The resistance therefore to electrical discharge through such conductors is, as compared with continuous rods, very considerably increased; a lightning conductor, under any form of chain, is therefore an inadequate substitute for a continuous rod, although in many cases it may be found convenient.

81. The difficulty of defending ships from lightning has frequently engaged the attention of learned

bodies, and in the year 1790 M. Le Roi visited the sea-ports of France, by the direction of the government, with a view to the further improvement of lightning conductors and their employment in the naval departments*. This philosopher strongly insisted on the necessity of giving marine conductors a more permanent and fixed character, and he therefore proposed to lead links of copper, joined by intermediate rings, in divided stages along the rigging, fixing each stage to the successive masts one over the other, and finally to the copper on the ship's bottom. This form of lightning conductor was carried out in the French ships *L'Etoile*, *Astrolabe*, *Résolution*, and some others. He admits, however, that the chains did not stand the working of the rigging, and therefore he finally led them along by the mast. They appear to have protected the ships in many storms of lightning.

In the year 1824 the French employed conductors of wires, twisted together in the form of cordage. They applied them along the rigging, from the vane rod to the ship's side, where they were connected with a plate reaching to the sea, as had been proposed by M. Le Roi†. These ropes have been lately recommended by several persons to be employed in the naval and mercantile marine of this country, the construction of such ropes having been wonderfully improved by Mr. Smith, who has obtained a patent for wire cordage generally.

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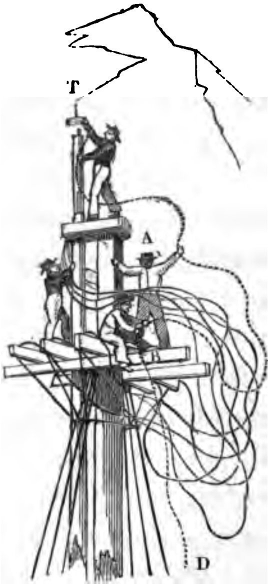
* *Histoire de l'Academie de Sciences*, 1790.

† Report of M. Gay Lussac to the Royal Academy of Science.

82. It is however extremely doubtful, whether any form of conductor of small dimensions, applied as rigging, and dependent on the sailors for its due application, and for the requisite attention to it, can ever be a perfect security, especially when we consider the difficult positions in which ships are so frequently placed. A small line of twisted wire loosely traversing the masts or rigging, and fixed to the truck, is exposed to great mechanical violence, besides which it is incompatible with the safety of those who may be required, in dangerous cases, to handle it. Let any one picture to himself a heavy gale, a pitchy dark night, squalls of wind with lightning and thunder,—a very common case,—and that it becomes necessary to make certain changes in the masts and sails; as, for example, to strike the top-gallant masts and get them on deck. In this case the men are necessarily exposed aloft on the topmast cross-trees, an altitude of one hundred feet or more, as represented in the annexed figure 35, the ropes, together with the wire conductor, blowing about in various ways and involving the men in the bights or curves of it; now it becomes requisite to remove and disengage the conductor and the truck to which it is attached, at which instant the ship is struck by lightning. What would be the consequence? The seamen engaged in handling the conductor and rigging must be either destroyed or

seriously hurt, since it is quite evident, from the known laws of electrical discharges (44), that in the case of the line becoming slack and tortuous, the passing shock would divide upon all the conducting matter in the vicinity of the conductor. In short it is easy to see that in the position given in the cut, the course of the lightning would be through T A B D, and would be resolvable into the phenomena of discharge described in fig. 17, more especially when we know that the resistance through small and comparatively long wires is considerable (68).

Fig. 35.



A great variety of cases of this kind might be adduced, and evidence is not wanting, to show the great danger of handling such conductors in thunderstorms. Thus three seamen, in the act of applying a linked conductor on board one of the American ships of war in the Mississippi, were struck dead*. Two men in the French frigate *Calypso* were struck down in the chains, in consequence of their forming a line of discharge between the wire rope and the sea†, and in *La Junon* a stroke of lightning, as already observed (68), divided between the wire rope and other channels of conduction near the deck and struck down many of the crew‡. So long as such conductors continue in use, seamen will at all times be exposed to these accidents, because the wire is but partially applied.

83. The precarious nature of temporary forms of conductors applied as loose rigging, and their liability to be disregarded or neglected, will be evident from the following facts:—

When the packet ship *New York*, already mentioned (34), was struck by lightning the first time, the conductor was in its box below, and it was only got out just in time to parry a second discharge, which however shook it in pieces. Hence the ship remained as at first undefended against further attacks (36). The consequences of the first discharge were, considerable damage to the mast and hull, the butts of three five-inch planks having been started in the side. A third discharge might have led to the destruction of the vessel.

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* *Shipwreck by Lightning Report*, &c. p. 81. † Idem, p. 21.

‡ *Annuaire* for 1838, p. 515.

His Majesty's ship *Madagascar*, already referred to (36), experienced five destructive discharges within the space of two hours.

His Majesty's ship *Kent*, of seventy-four guns, whilst cruising off Toulon in 1811, had usually the conductor fixed to the mainmast: the constant working of the mast and rigging damaged the chain so much that it was obliged to be taken down for repair. During this time the ship was struck by lightning, the mast set on fire and totally destroyed, and several men lost their lives*.

A similar result ensued on board His Majesty's ship *Perseverance* in the year 1790; the conductor was removed in order to repair the rigging, and an electrical discharge struck the ship and shivered the mast†.

Captain Chads, R.N., stated that, from the extreme liability of the chain to accidents, he considered it an inadequate protection. He commanded His Majesty's ship *Andromache* for nearly four years, during which time "scarcely a day passed without the conductor requiring repair‡."

Captain Chappell, R.N., stated, that he had known instances in which the state of the weather rendered it impossible to get the conductors properly applied. This happened in His Majesty's ship *Captain*, of seventy-four guns, in 1809§.

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* *Report and Evidence*, p. 92.

† Idem, p. 30.

‡ Idem, p. 30.

§ Idem, p. 31.

Captain the Honourable F. Grey stated, that whilst in the command of His Majesty's ship *Jupiter*, of fifty guns, the greatest difficulty was experienced in keeping the chain in its place at the time of a squall off the Cape of Good Hope*.

In December, 1834, His Majesty's ship *Leven* was struck by lightning on the coast of Africa; the lower extremity of the conductor being left in its box in the chains†. The channels of the ship were in consequence destroyed. This neglect to make the connection with the sea perfect, is a very common occurrence.

Mr. Tonna stated, that he one night found the conductor coiled up and secured to the lower rigging in His Majesty's ship *Rainbow*‡.

Admiral Wise was never satisfied with the efficient application of the conductor. On one occasion on board His Majesty's ship *Thunderer*, in September, 1834, he found it requisite to shift the position of the lower end of the chain. The man who carried out the orders had not let the conductor out of his hand more than a few minutes, when a violent shock of lightning rushed down it into the sea. To prevent such an exposure of the men in future, he judiciously attached the conductor to a plate of copper fixed to the ship's side. "I was now certain," says he, "that it was secure below, if I could but be satisfied that it was equally so aloft, but this can never be the case with conductors, fitted as they now are in the navy*."

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* *Report and Evidence*, p. 30.

† Communication to the author from a naval officer.

‡ *Report*, p. 26.

In hauling up the main-sail in a merchant ship, commanded by Captain Winn on the coast of America in the year 1770, the sheet-block struck so violently against the backstays to which the conductor was fastened, that it broke it in two places†.

The ship *Blakely*, of Liverpool, lately supplied with conductors of wire-rope, had her main-royal mast shivered by lightning, in consequence of the captain having neglected to apply the conductor from the mast-head‡. Had the masts and rigging been carried away, or taken down for repair, the application of the wires to the main-top mast might have been as easily neglected. In the year 1840, two wires, applied as conductors in Her Majesty's ships *Belleisle* and *Impregnable* in Plymouth Sound, were rubbed through by the repeatedly striking and raising the top-gallant masts, and were returned to the dock-yard as unsafe§.

Conductors for Ships, under a fixed and permanent Form.

84. These cases prove very completely the insecurity of temporary methods of protecting ships by conductors applied as rigging, and dependant on the officers or crew of a ship for their due application,

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* *Report*, p. 68.

† *Phil. Trans.* for 1770.

‡ Smith's paper, read to the Society of Arts, December, 1842.

§ Official notice.

and for proper attendance on them,—a difficulty much increased by the absolute necessity of providing a conductor for each mast; and the consequent attendance on three such conductors, which must be watched and cared for, in all the various casualties to which a ship is exposed. They hold out a sufficient inducement, for attempting the application of conductors to shipping, under a form so capacious, and so permanently fixed, as to render them an integral part of the vessel, and independent of the crew under all circumstances.

With this view, a proposal was submitted, by the author in the year 1821, to the Lords of the Admiralty, through the Comptroller of the Navy, to make the masts themselves virtually lightning conductors, by incorporating with them a double set of copper plates, in such a way as to produce an elastic metallic line along their surface, capable of resisting any strain which the spars themselves could support; and finally to connect these plates with bands of copper leading through the side under the deck-beams, and with the large bolts leading through the keels and keelson; and including by other connections all the principal metallic masses employed in the construction of the hull*; thus rendering the ship quite safe from any discharge of lightning which would be likely to fall upon it, by bringing the whole fabric as nearly as possible under the conditions most favourable to perfect security (57). It appears from the official report of naval and scientific men, appointed by their Lordships, with the sanction of the House of Commons, to investigate this subject, that any explosion of lightning falling on a ship so circumstanced, would disappear entirely at the mast-head, and that consequently all intermediate explosion or damage such as commonly occurs,would be completely avoided. The system was further proved efficient for every new position or condition of the masts and hull; and has been so well confirmed by experience, that it is now pretty generally adopted in Her Majesty's ships. A brief account of this method of Marine Lightning Conductors, with the mode of application, may not be altogether unimportant as a conclusion to this section of our work.

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* Vide figs. 38, 39, 40, pp. 144, 145.

85. Sheets of copper varying from 1·5 to five inches wide, and one-eighth and one-sixteenth of an inch thick, are cut by a circular saw into parallel plates four feet in length. These have holes drilled and countersunk in them at distances of six inches apart, on alternate sides, by which they are secured to the masts by short copper nails; a shallow groove is ploughed out of the after side of each mast, by means of planes constructed for the purpose, and a straight batten. The plates being a little rounded (in a moulded block of wood) to the form of the mast, are beaten and fixed into these grooves by appropriate tools; so that they are closely incorporated with the round of the spar, and form, as it

were, a portion of it. The plates are inserted into the grooves in a double series, placed so as to admit of the continuous portions of the one, falling under the butts or joints of the other, as in the annexed fig. 36, in which the plates are represented in a loose state for the sake of clearness.

Fig. 36.

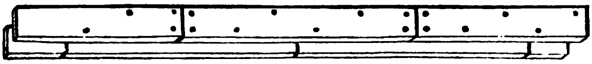
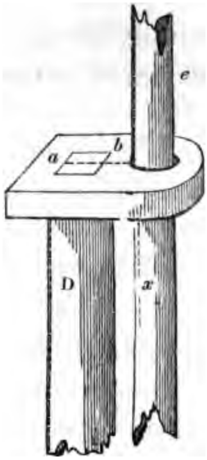


Fig. 37.

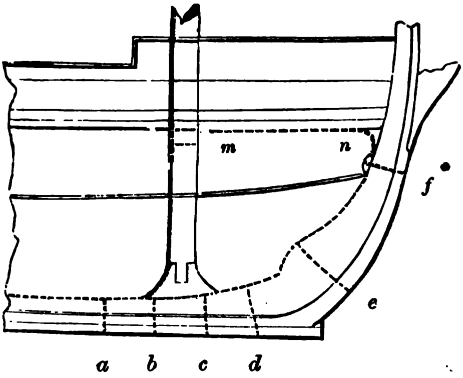


The series when combined is turned over the heads of the respective spars, and also round the termination of the mast in the step on the keelson, as shown in figs. 37, 38, 39, 40.

The caps *a b* (fig. 37), and the hole *b* in them, through which the moveable masts *e x* slide, are furnished with similar plates; these are led from the square hole at *a*, by which the cap *a b* is fixed to the head of the mast D, into the round hole at *b*, and there is a lining of copper in this part of the hole next the conductor at *b*, by which the metallic line is continued to the next mast D.

The bolts, *a b c d e f* (figs. 38, 39), passing through the ship, and in which the general line of conduction terminates, are clenched upon metallic rings, and plates in connexion with the copper sheathing, and there are additional bands, *m n* (fig. 38), leading from the foremast and mizen-mast directly to the stem or stern under the decks; other bands, *g h*, traverse the beams, as in fig. 39, and they all terminate in the sea by bolts clenched on the copper sheathing.

Fig. 38.



In the annexed figures, 38, 39, 40, fig. 38 represents the conductor as applied to the foremast. Fig. 39 is a section suited to the beams abaft each mast. Fig. 40 represents the line of conduction *a b c s* complete from the mast-head.

86. It may be immediately perceived in this

arrangement, that in whatever position the sliding masts can possibly be placed, whether in a state of

Fig. 39.

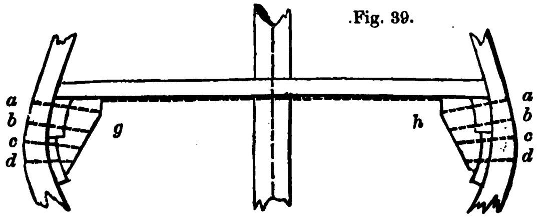
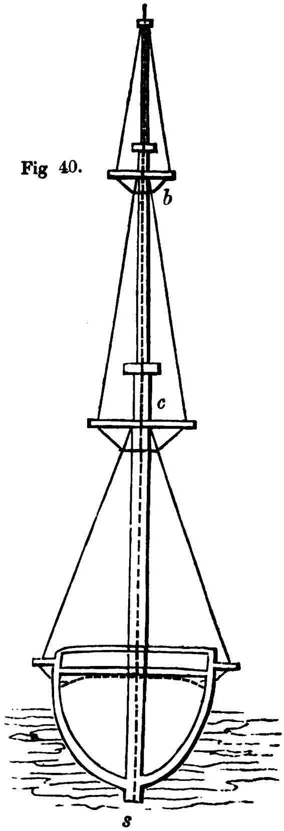


Fig 40.



elongation, as in fig. 40, or otherwise partially lowered, as in fig. 37, there will still always exist a complete line of conduction, of a permanently fixed and capacious kind, extending from the highest points to the great masses of metal in the hull and from thence to the sea. The mere position of the moveable or sliding masts, or the removal of either of them, is not in the least degree inconsistent with the action of such a conductor; from the very nature of the arrangement, a continuous portion connected with the sea must always be present, whatever damage or change may occur in the upper parts. In the case of the topmasts or top-gallant masts being partially lowered, any portion, such as *a b* (fig. 41) below the point of junction over the cap at *a*, is, in accordance with the principles already demonstrated (48), quite out of the line of action. Indeed, this may be experimentally and pleasingly illustrated, by laying down on paper, as in fig. 41, some narrow slips of leaf gold in the same relative position as that in which the conductor would in such a case be placed. If a shock be now passed over these slips from *p* to *n*, the result will be as in fig. 42; the gold will be destroyed or blackened in the line *p a n*, the portion *a b* will be untouched; this portion, *a b*, therefore is, in respect of the passing charge, the same as if it did not exist. It is further evident, that in this system, the conductors are altogether independent of the crew, they are always in place, and are therefore always ready to meet whatever danger from lightning the ship may chance to encounter.

Fig. 41.

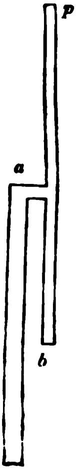
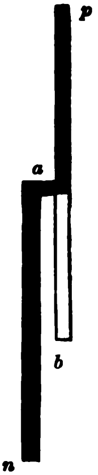


Fig. 42.



87. Although objections have been occasionally advanced against this system, on the ground that

lightning is invited into a ship, and that danger is of necessity attendant on the discharge through the hull*, yet such objections are not to be maintained in the present state of this department of science; more especially as they are contradicted by the whole course of experience. That heavy electrical discharges may be with safety conducted through solid bad conductors, and be discharged and dispersed by the metals in a ship's hull, is not a matter of speculation, but the result of experience.

In the case of His Majesty's ship *Pelican* (34), Captain Ward states "that the lightning, after shattering the higher masts in fragments, passed down in an irregular spiral form, grooving and indenting the lower mast to the keel; and that the discharge must in this, as in most other cases, have found conductors in the bolts of the ship's bottom, to convey it to the sea.".

Admiral Hawker states, that when His Majesty's ship *Mignonne* was struck by lightning in the West Indies, in 1804, "the topmast was scattered in splinters by the discharge, and the mainmast split open down upon the keelson:" here again the long bolts passing through the keel arrested the explosive action†. Indeed it was long since remarked, that whenever the electrical discharge had reached the well, no further damage ensued‡.

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* *Report and Evidence on Shipwreck by Lightning*, pp. 26, 27.

† For similar effects, vide *Nautical Magazine* for June, 1842.

‡ *Phil. Trans.*

Her Majesty's revenue cutter *Chichester* was struck, in February, 1840, in Kilkerran Bay, by a flash of lightning, which severely damaged the mast, struck down all the bulkheads below, threw up the heavy iron-grated skylight, and by its expansive force actually lifted the deck six inches from the beams. Now this heavy stroke of lightning, was proved to have passed into the sea by the long copper bolts in the bottom and side, without doing the slightest damage to the timbers and planking. At the points where the discharge escaped from the ends of the bolts, it exploded on the interval of the tarred paper covering the planking, in consequence of which the copper sheathing was burst open; "one of the bolts had a round drop hanging on the end of it, as if melted*."

Instances of this kind are very numerous, and completely establish the protecting power of conducting bodies so far as they extend. Besides, the application of fixed conductors of this kind to shipping, evidently rests upon the same general principles, as all other lightning conductors, and they have further the advantage of the greatest possible freedom of action, in virtue of their terminating immediately in the sea: a great number of Her Majesty's ships fitted with them have, during the last twelve years, been exposed to shocks of lightning in all latitudes, and under a great variety of circumstances. In no case have they been damaged, nor have they been assailed by lightning in a greater degree than other ships, whilst in cases in which heavy discharges of lightning have fallen upon them, the most perfect protection has been afforded.

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* Official communication from Captain Stewart to the Board of Excise.

Captain Sulivan, R.N., thus describes the flash of lightning which fell on Her Majesty's ship *Beagle* at Monte Video, and which he witnessed during his period of duty on deck. "Having," says he, "been on board His Majesty's ship *Thetis* at Rio de Janeiro a few years since, when her foremast was entirely destroyed by lightning, my attention was always very particularly directed to approaching electrical storms, and especially on the occasion now alluded to, as the storm was unusually severe. The flashes succeeded each other in rapid succession, and were gradually approaching, and as I was watching aloft, the ship became apparently wrapt in a blaze of fire, accompanied by a simultaneous crash which was equal, if not superior, to the shock I felt in the *Thetis*. One of the electrical clouds by which we were surrounded had burst on the vessel, and as the mainmast at the instant appeared to be a mass of fire, I felt certain that the lightning had passed down the conductor on that mast. The vessel shook under the explosion, and an unusual tremulous motion could be distinctly felt. As soon as I had recovered from the surprise of the moment, I ran below to state what had happened, and to see if the conductors had been affected, when just as I entered the gun-room, Mr. Rowlett, the purser, ran out of his cabin (along the beam of which a main branch of the conductor passed), and said he was sure the lightning had passed along the conductor, for at the moment of the shock he heard a sound like rushing water along the beam. Not the slightest ill consequence was experienced, and I cannot refrain from expressing my conviction that, but for the conductor, the results would have been serious*."

88. These somewhat lengthened but still requisite details, may perhaps convey to many an impression prejudicial to the simplicity and economy of the system of conductors here recommended for shipping. Such an impression will, however, be found on examination to be erroneous; the method of fixing the plates now adopted in Her Majesty's dock-yards will be found extremely expeditious and easy, whilst the expense bears a very small proportion to the value of the ship, and quite vanishes when we consider how important is the protection afforded. The cost of a first-rate, with all her stores, is not less than 170,000*l.*; she carries full nine hundred men, and she is intended for the defence of one of the greatest maritime nations which has ever existed. Now, the protection of this splendid machine against one of the most fearful calamities to which she is exposed, may be attained at a cost of less than 100*l.*, *i. e.*, the expense of labour in fixing the conductors to the ship, and the loss

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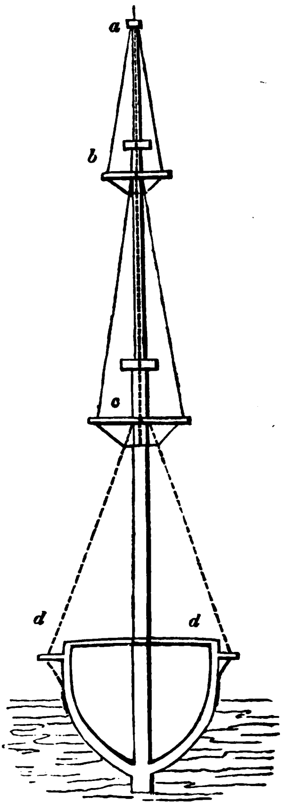
* *Nautical Magazine*, for January, 1829.

upon the wear of the copper material, which is always reconvertible and of a constant value. Her Majesty's Navy once furnished with such conductors, as an integral part of the ships, little or no further expense will be requisite, as the hulls will be always ready to receive masts, fitted with the same conductors which have been already used in other ships, whose services have for the time ceased: it is hence a mere affair of transfer from ship to ship.

Fig. 43.



89. In the case of merchant shipping, where it may be found inconvenient to prepare the hulls and lower masts as just recommended, the advantage of a continuous conductor, permanently fixed, and independent of the crew, may still in a great degree be attained by the method represented in fig. 43, in which fixed lines of metal are incorporated, as before, with the higher masts, as *a b*, *b c:* and from the point *c*, at the head of the lower mast, flexible wire ropes, *c d*, *c d*, of half an inch in diameter, are led as fixtures down the after swifters to

the ship's side, where they are attached to a plate of copper connected with the sea. This portion of the rigging being generally fixed, but little interference with the conducting line on the part of the crew would be requisite.

It would not be difficult, in this way, to apply a light tube of copper of three-fourths of an inch in diameter, which might be secured to the rigging by means of small supporting cleats, through which it might pass. A method of this kind was submitted to the Lords Commissioners of the Admiralty, in the year 1830, and again in 1837, and it would be no doubt very efficient, although not so perfect as when the conductor is carried down the whole mast and throughout the hull.

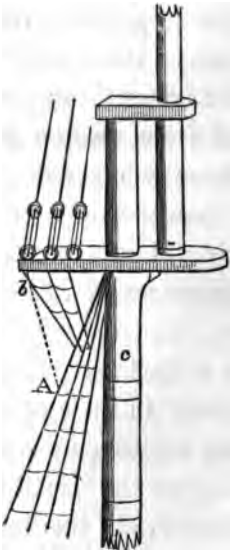
With respect to the defence of shipping from lightning, it may with certainty be predicted, that until some form of lightning conductor be adopted of a fixed and permanent kind,—of great electrical capacity, quite independent of the crew, so as to be always in place, and always ready under all circumstances, to meet unexpected danger, and at the same time be so applied, as to admit of every possible motion or contingency attendant on the masts and rigging, without imposing upon the seamen the necessity of watching or handling it, to their great peril and annoyance,—that until these conditions be satisfied, our ships will still remain exposed to the dreadful effects of lightning, their rich cargoes frequently lost, and our national interests greatly prejudiced. Lightning conductors for ships, under any form of rigging, have always fallen into disuse; and however much a temporary excitement may, in a few cases, stimulate sailors to look after them, they will still eventually become neglected, since it has been found, by experience, that seamen believe they may be as well without them, as incur the risk and trouble they involve.

90. A question of no small consequence here presents itself for consideration, viz., the probable effect of metallic rigging applied in various ways to the masts of ships. In treating this question, we have to take into consideration the mode of application of the rigging, the amount of its conducting power, and its perfect connection with the sea. If we conceive the metallic ropes to be always in their places, and to be continued from the masthead fairly to the water, we fulfil the principal conditions of a good lightning rod, but this is not likely to be the case. Standing shrouds and rigging would probably be covered over with tarred yarns, and be protected from chafing by a similar application. If the iron wires should become rusted, their conducting power would be very greatly decreased; and it would not be very easy to guard against the consequences of a discharge of lightning over such rigging, especially to the seamen in the act of going aloft to furl the sails: they would be all more or less included in lines of small resistance to the progress of the discharge.

Take, for example, the position of a seaman in the act of passing from the lower rigging at A (fig. 44) over the inclined ropes A *b*. He would evidently form the third side of the triangle *b c* A, and would hence be the shortest line of conduction from the top-mast shrouds to the rigging below, and would therefore be involved in the electrical circuit, and be so far in a position of great peril.

All this is yet to be determined by the results of experience, and the many contingencies and casualties to which a ship so rigged would be exposed, shows how difficult it is to provide for the safety of the general mass in lightning storms at sea, except by some such system as that we have just described (84), and which would certainly, under any condition of rigging, ensure perfect protection both to the ship and crew.

Fig. 44.



It may not be useless to close these remarks with a short abstract of the following cases of damage by lightning on ship-board, bearing on this question:—

On the 20th of March, 1839, Her Majesty's steam frigate *Blazer*, having chain rigging, was struck by lightning off Cape Beyrout, in the Mediterranean. The discharge fell on the main-cap, and split it open. It broke in pieces the chain halliards which held the main-gaff, so that the whole fell on the deck. Then descending the chain rigging on both sides of the mast, it shivered on one side a deck plank, and, about three feet above the water, blew out thirty feet of the planking of the sponsons an inch and three quarters thick: on the other side it shivered a quarter-deck rail of African oak, four inches thick, and struck a hole, about the size of a six-pound shot, through the bottom of a boat slung at the davits. The cabins were filled with a sulphureous vapour, and for a time the ship seemed on fire *. Fortunately there were only two persons on deck at the time; but supposing the seamen had been in the act of ascending the rigging, or engaged in handling any of the chain halliards or metallic ropes, their position would have evidently been a perilous one.

His Majesty's ship *Dædalus*, having been partly dismasted in a hurricane in the West Indies, in August 1809, was refitting in Port Royal harbour,

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* From the log of the acting master.

Jamaica, in October following. A new foremast had been just placed in the ship, the mizen-mast partly rigged, and preparations were making for shipping the mainmast. A thunderstorm occurred on the morning of the 13th, which struck the new foremast, and completely ruined it*.

Now supposing in this case that standing wire, or chain rigging had been hanging loosely over the mast-head, and that the riggers had been employed about it; it is not very difficult to predict the consequences, since we see by the preceding case what are the results of a dense discharge of lightning in passing from such rigging upon the body of the vessel. But now, by making the masts themselves perfect conductors, and providing free metallic communications between them and the masses of metal in the hull and sea, we evidently ensure protection from lightning under every possible contingency.

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* Ship's log, and remarks by Admiral Inglefield, who commanded the ship.

SECTION III.

RESULTS OF THE APPLICATION OF LIGHTNING RODS TO BUILDINGS AND SHIPS,

FROM THE PERIOD OF THEIR FIRST BEING EMPLOYED IN THE YEAR 1760.

Introductory Remarks—Whether Metallic Conductors have effectually defended Buildings, &c. against Lightning?—Whether Lightning Rods attract Lightning?—Whether pointed Conductors actually prevent explosions of Lightning?—The Phenomena observed, when concentrated discharge strikes upon a Conducting Rod.—Harmless character of the luminous appearances observed on Lightning Rods—The Phenomenon termed Lateral Discharge—Division of the Charge—Instances in which Buildings having pointed Lightning Rods are said to have been damaged by Lightning—Concluding Observations.

Introductory Remarks.

91. In the preceding sections we have considered the physical conditions of a thunderstorm, and the laws and mode of operation of electrical discharges. From these inquiries we have deduced certain practical results relative to the employment of metallic substances under the form of lightning rods, as a means of protection against the calamitous effects of lightning.

We now propose to examine such evidence as we possess of the efficacy of lightning rods, whether they have met all the conditions required for perfect security against discharges of atmospheric electricity, without endangering the buildings to which they are applied, and finally to inquire into the validity of certain popular objections to their general employment.

It may be perceived, that in all these researches we have adhered carefully to the safe and beaten path of inductive science: in no case has any advance unwarranted by facts been attempted. The same caution will be observed in examining the different views which have been entertained of the efficacy and action of lightning rods. For, as it has been beautifully remarked by Lord Bacon, the great father of inductive science, " Man, who is the servant and interpreter of nature, can act and understand no further, than he has either in operation or in contemplation observed of the method and order of nature."

Whether Lightning Rods and other Metallic Conductors have effectually guarded Buildings, &c. against Damage by Lightning.

92. The cases in which continuous metallic conductors have afforded complete protection from lightning, are by no means few or inconclusive. We shall proceed to detail some of the most remarkable of such instances. Between the years 1820 and 1830 several church towers in Devonshire were struck by lightning: amongst these were Shaugh church, on the southern border of Dartmoor; Alphington church, near Exeter; Marlborough and Kingsbridge churches, on the southern coast; and Charles church, at Plymouth: of these, one only was protected by a lightning rod, viz., the church at Plymouth. Now it is an important fact, that although the conductor was broken in pieces by the shock, as already stated (66), this was the only instance in which the church and tower escaped damage.

The church of St. Michael, at Charlestown, was very frequently struck and damaged by lightning previously to the year 1760, when a lightning rod was applied to it. It has never suffered since*

The Dutch church at New York was struck by lightning in the year 1750, and again in 1763. The electrical discharge in each case passed over the metallic connections between the hammer of the bell and the works of the clock,—as in the cases of Brixton and St. Martin's churches, already mentioned (57); in both instances portions of these connecting wires were melted, and the building was damaged.

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* *Phil. Trans.* vol. LXIV. p. 133.

In 1765, an iron rod was applied from the stem of the weather-cock along the exterior of the building, and continued to the ground. During this year there again fell on it a heavy stroke of lightning: the building, however, was not in the least degree damaged, nor was any effect observable on the wire connecting the bell with the clock*.

The chapel of the château of the Count Orsini, in the province of Carinthia in Hungary, being on an elevated site, received such frequent damage from lightning, that divine service was no longer celebrated there. In the year 1730 a single discharge occurred, which at once laid the bell-tower in ruins. In 1778 the building was again nearly demolished by a similar explosion, and was again rebuilt. The great discovery of Franklin, however, began now to be appreciated, and a pointed lightning rod was applied to the tower. During the next five years, it was only once assailed by lightning, and then no damage ensued; nor does the building appear to have suffered since†.

The royal château at Turin was frequently damaged by lightning up to the year 1772, when Beccaria applied lightning rods to its principal roofs. Since that time, although frequently menaced by thunderstorms, it has remained uninjured*.

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* *Annuaire* for 1838, p. 604. † Rozier, xxiv. p. 323.

The fine tower of St. Mark at Venice, more than three hundred and forty feet high, was repeatedly damaged by lightning, to which, from its elevated position, it was greatly exposed. This tower terminates in a pyramid eighty-seven feet high, on which stands a wooden figure of an angel, covered with copper. The detached pieces of iron employed in its construction produced (as at St. Bride's church in London) (54) very destructive effects. It was damaged severely in 1388, at which time it was a wooden structure. In 1417 it was set on fire by lightning, and destroyed. In 1489 it was again struck, and the pyramid reduced to ashes. It was now rebuilt with stone. In the years 1548, 1565, and 1653, it again suffered from the same cause, and in 1745 a stroke of lightning fell on it with such tremendous force, that the whole tower was nearly ruined: it was rent in no less than thirty-seven places. The cost of repairs in this instance amounted to eight thousand ducats. In the years 1761 and 1762 it was again severely damaged†.

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* *Annuaire*, p. 605; MARBUCH, *Encyk. der Exp. Physik*, vol. i. p. 314.

† Extract from registers of the city; ARAGO, *Annuaire* pour 1838.

We have here sufficient evidence of the frequent effects of lightning on this building, whilst unprotected by a conductor. Now in the year 1766 a lightning rod was applied along the exterior of the tower, reaching from the metallic figure on the top of the pyramid to the ground. Since this period we find no further account of its having suffered in the least degree from the effects of lightning.

We have already noticed the application of a lightning rod to the beautiful tower of the cathedral at Sienna (59), which although frequently struck and damaged by lightning before the application of the rod, has not since experienced any ill consequences, although struck by lightning in a similar way.

In ROZIER'S *Journal*, vol. xxii., we find an interesting and circumstantial account of a powder magazine at Glogau in Silesia, struck by lightning in May, 1782, and defended by a pointed lightning rod. "The flash was seen to leave the cloud and strike upon the rod; it appeared to envelope the whole building in electrical fire. The sentinel on guard lost his senses for some minutes, but no damage ensued." The conductor terminated in a well of water.

It may be well to contrast this result, with the results in other cases, in which discharges of lightning have fallen in a similar way on magazines of gunpowder, not provided with lightning rods.

In March, 1782, about the same period, a discharge of lightning fell on a magazine at Fort Marlborough, in Sumatra, not having a lightning rod, and set fire to four hundred barrels of gunpowder*.

The magazine in the vaults of the church of St. Nazaire at Brescia, a large depôt of gunpowder belonging to the republic of Venice, shared a similar fate, in August, 1769. The electrical discharge struck the tower, and descending to the vaults, exploded above 207,600 pounds of gunpowder†. By this dreadful catastrophe above three thousand persons perished, and nearly one-sixth of the beautiful city of Brescia was destroyed.

A similar accident occurred to a magazine at Malaga in August, 1780, and at Tangiers, in May, 1785. At Luxembourg, in June, 1807, a magazine of gunpowder, built in former times by the Spaniards on a solid rock, was struck by lightning and blown up: more than 28,000 pounds, or about twelve tons of gunpowder were fired, by which the lower part of the town was laid in ruins‡.

In September, 1808, a magazine near Venice was exploded by lightning, and in November, 1829, another at Navarino§. In the East Indies there have been very lately two explosions of this kind, viz., a magazine at Dum Dum, and a corning-house at Mazagon: both these establishments were unprovided with lightning rods.

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* MARSDEN'S *History of Sumatra*, third edition, p. 19.

† ARAGO, *Annuaire* 1838, p. 483.

‡ Idem.

§ Report by Admiral Rosamel to the Minister of Marine, November, 1829.

Now it is to be observed on the contrary, that although such rods have been employed for the defence of these buildings from lightning for more than seventy years, yet in no instance in which a lightning rod has been applied has any explosion happened.

The protecting effect of a lightning conductor was well shown at Philadelphia, United States, in July, 1770: a severe thunderstorm overspread the city, and produced electrical discharges in four places, so that three houses and a merchant ship in the river were struck by violent detonations. One of the houses had a pointed lightning rod, and escaped damage: the other houses, on the contrary, together with the merchant ship, suffered considerably. On examining the point of the conductor on which the lightning fell, it was found to have been melted*.

The old church of St. Paul's, in London, not having been provided with a lightning rod, was twice struck by lightning and damaged. The present still more elevated building, having lightning conductors of great magnitude, has never suffered from this source of danger†.

93. In addition to these instances of the operation of pointed metallic rods, in defending buildings

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* *Annuaire*, p. 609.

† *Phil. Trans.*

against damage by lightning, it may be observed, that edifices furnished with continuous metallic masses, either with a view to utility or ornament, have seldom if ever suffered from atmospheric electricity.

The learned orientalist Michaelis states, that the temple of Jerusalem had not, during ten centuries, experienced a single condensed electrical explosion. Now in examining the accounts given of this building, it appears to have been covered inside and out with burnished plates of metal,—Josephus says gold. The top was covered with a thick gilding, and bristled with long pointed iron or steel spikes. The object of this appears to have been to prevent birds from settling on the gilded dome. Under the court of the temple were cisterns, which received the rain from the roof through metallic pipes. A more complete system of efficient conductors of lightning could not have been devised. The conditions we have insisted on (57), viz., that of bringing the building as nearly as possible into the same electrical position that it would be in, were it a complete metallic mass, are here fully satisfied, and we accordingly find, that this building never sustained the slightest damage from lightning, although from its elevated position it was exposed to the frequent and terrible storms of Palestine. It is more than probable, from the circumstance of the roof having been covered with cedar, both within and without, that a heavy stroke of lightning falling on it, would but for the metallic coatings, have set it on fire. When we consider, (as observed by Arago,) how carefully the ancients recorded instances of damage done to their buildings by lightning, it is impossible to explain the silence of historians on this point, except by admitting that the Jewish temple had never suffered in thunderstorms.

A parallel instance is found in the case of the cathedral at Geneva. This building, the most prominent and elevated in the whole city, has for more than two centuries enjoyed a perfect immunity from the effects of lightning, whilst the bell-tower of St. Gervais, situated much lower than the cathedral, has been frequently struck and damaged.

In the year 1771, Saussure investigated the cause of this, and on examination found, that the great central tower of the cathedral, built of wood, and which had existed above three hundred years, was completely covered from its summit with tinned iron plate: this communicated at the base of the tower with the various metallic masses about the roofs, and lastly by metallic pipes with the ground, thus forming an extensive and complete series of conductors, equivalent to the transmission of the most powerful electrical discharges.

We have already had occasion to notice the Monument near London Bridge (77), which by its construction has an uninterrupted series of conductors reaching through its interior, from the urn on its summit to the earth. This building has remained safe amidst the many furious thunderstorms which have, since its erection in 1677, frequently spread over the metropolis, and damaged some of its principal edifices.

94. It may be observed as a general truth, that buildings in any way cased or supplied with metallic substances continued to the ground, invariably escape damage from lightning; and that where such metallic coverings or connections are only partially applied, the damage commences where they cease, and on the contrary, ceases where they commence. Thus one of the large granite chimneys, above a hundred feet high, at the Royal Victualling Yard, near Plymouth, was, on the 25th of May, 1841, rent by lightning sixty feet down, as far as the copper roofing of the building in connection with it: here all damage ceased, the copper having free conducting communication with the earth by the metallic pipes for carrying off the rain.

The effects of lightning on St. Peter's church in London, in the summer of the year 1774, are most remarkably conclusive on this point. The spire of this church was surmounted by a large key of gilded copper, and was covered with lead as far as the brick tower; accordingly so far no damage ensued, but between this and the leaded roof of the church the tower was much rent. At the roof, the metallic conduction again commenced, and continued to the ground; and here again the damage ceased*.

95. Such are some of the most striking facts bearing on the protective operation of lightning rods

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* *Phil. Trans.*, vol. LXIV., p. 133.

on buildings: we will now proceed to examine their influence on shipping.

In the year 1839 the Lords Commissioners of the Admiralty appointed a naval commission to investigate the best method of applying lightning conductors to Her Majesty's ships. After a very elaborate inquiry, they drew up a report on this important question, extending to more than eighty folio pages, and containing a valuable mass of oral and documentary evidence, received from naval officers, men of science, and other competent persons. This report was laid on the table of the House of Commons, and in February 1840 was ordered to be printed. One of the points to which the commission directed its attention was this: "Whether in cases in which ships *not having* lightning conductors have been struck by lightning, it appears that other ships in company *having* lightning conductors, have either not been struck, or have escaped injury." The following are some of the cases which were brought under the notice of the Commissioners:—

In 1815 His Majesty's ship *Norge*, was severely damaged by lightning, whilst the *Warrior*, of seventy-four guns, with a pointed conductor, lying close to the *Norge*, received no injury. The electrical action in this case illuminated the linked portions of the conductor, and appeared to stream down into the sea. There were many other ships in the harbour, but none received any damage except one, *and this ship was the only one which had not a conductor.*

In February, 1824, His Majesty's ship *Milford*, not having a lightning conductor, was struck by lightning in the Hamoaze, Devonport, and damaged, whilst His Majesty's ship *Caledonia*, of one hundred and twenty guns, about eighty fathoms distant, having pointed conductors, escaped.

In September, 1824, His Majesty's ships *Phaëton* and *Adventure* were lying at Gibraltar Mole: the *Phaëton* had not conductors, but the *Adventure* had: the ships were within a cable's length of each other. Under these circumstances the *Phaëton* was struck and damaged by lightning; the *Adventure* escaped.

In January, 1830, His Majesty's ships *Madagascar*, *Ætna*, and *Mosquito*, were about to come to an anchor off Corfu. A violent thunderstorm arose, which struck and severely damaged the *Madagascar* and *Mosquito*, the ships without conductors; the *Ætna*, which had a conductor at the main, although struck by lightning repeatedly on this mast, escaped.

In 1837, the *Cochin* tank-vessel, in Trincomalee harbour, had her foremast shivered by lightning, whilst Her Majesty's ship *Winchester*, about two cables length distant, escaped. The *Winchester* had a conductor, and the lightning was observed to stream down it; the tank-vessel on the contrary, was undefended.

In November, 1837, the *Pelican*, of sixteen guns, without a conductor, was struck by lightning on the coast of Africa, and damaged; the *Waterwitch*, another of Her Majesty's ships, at anchor within a short distance, escaped.

In March, 1838, Her Majesty's ship *Ceylon*, in

Malta harbour, was struck by lightning, which shivered the foremast; she had no conductor. Her Majesty's ships *Talavera* and *Bellerophon*, both furnished with lightning conductors, escaped, as did the sheers for masting ships, which were similarly armed. This instance is the more remarkable, from the fact that the *Ceylon*, as a receiving ship, had only a short pole above her foremast, whereas the other ships, being fully rigged, their masts extended above one hundred and fifty feet into the air.

"In addition to these instances," say the Commissioners, "we beg to call their Lordships' attention to the case of the New York packet, laid before the Lord High Admiral in 1827 by the Navy Board. It appears that on her passage to Liverpool, in 1827, this ship was struck by lightning, and sustained considerable injury. The conductor was not up at the time; but the weather continuing stormy, it was got out, and triced up to the mast-head. The ship was a second time struck by a most severe stroke of electricity, which fused the chain, and passed into the water without doing further damage." (34) (71).

96. The following are some additional cases conclusive of the efficacy of lightning rods as a defence against lightning, the ships having been fitted with pointed conductors fixed in all their masts:—

His Majesty's frigate *Dryad* was struck by lightning in a tornado on the coast of Africa in 1830. Commander Turner says, "that the discharge fell on both the fore and mainmasts with a loud whizzing sound; the thunder was nearly simultaneous with the lightning, and the ship appeared enveloped in flames."

His Majesty's frigate *Druid*, at Rio Janeiro, in 1832, encountered awful lightning, which was "conducted safely down the conductors on the fore and mainmasts*."

His Majesty's *Asia*, in the Tagus, in 1831, was assailed by lightning during a squall with heavy rain; the electrical explosion passed off safely upon the conductor on the mainmast†.

Her Majesty's frigate *Talbot*, in July, 1842, was struck by lightning soon after getting under weigh at Sheerness. The lightning was observed to fall immediately on the conductor when the cloud burst over the mainmast head‡.

The cases of the *Beagle* and *Actæon*, referred to in our second section (71), furnish very complete and important evidence of the beneficial operation of pointed conductors.

Lieutenant Sulivan, who had witnessed the effects of lightning in shattering the mast of His Majesty's ship *Thetis*, happened to be on duty at the time the electrical discharge fell on the *Beagle* (71); he states that, "when the clouds by which the ship was enveloped burst on the mast, the mast and ship appeared to be wrapped in a blaze of fire; the vessel trembled under the crash of the thunder, and a vibratory whizzing sound was heard along the conductors."

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* *Report of Commission*, p. 94.

† Witnessed by Mr. Sadler, the master of the ship.

‡ Reported to the Lords of the Admiralty.

Lieutenant Bonham, and Mr. May, the carpenter, who were both on deck when the *Actæon* was assailed by lightning (71), describe very similar effects. The discharges occurred within a fearfully short distance of the ship, and the flashes were so vivid, that the observers were for a time deprived of sight. When the ship was struck, the lightning was observed to fall immediately on the conductor; the crash of the thunder was intense and simultaneous with the lightning. The cutlasses stowed around the mast rattled in their stand, and there was a loud whizzing sound upon the conductor which appeared enveloped in electrical fire*."

These cases which have much in common, are characterized by well-known phenomena of electrical action; they have occurred in various parts of the world, at different times, and have been reported on by persons in no way interested in perverting the facts: hence no doubt can remain as to the decisive evidence they afford, of the protecting power of pointed conductors.

The Commissioners conclude their remarks on the first head of their inquiry in the following words: "Every search has been made for cases of injury sustained by ships fitted with conductors; and though several statements to that effect have been brought under our notice, *not one has been substantiated**."

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* Account by the master.

97. Finally, it is not unimportant to observe, that since the year 1829, above thirty of Her Majesty's ships have had pointed conductors fixed in all their masts. These vessels have been at sea, and exposed to severe thunderstorms in all parts of the world; and although, as we have just shown, heavy electrical discharges have fallen upon them, yet in no instance has any damage or inconvenience been experienced. On the other hand, about forty-one vessels, not fitted with fixed conductors, (more than one-fourth of the average number of ships at sea, or on foreign stations) are known to have been struck and damaged during this period.

As this must be considered one of the most important and extensive national experiments ever instituted with a view of testing the practical value of lightning rods, it may be satisfactory to give the names and stations of these ships.

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* This observation is limited to the protective effect of the conductor on the mast to which it is attached, as in some few instances damage has ensued to one of the masts of a ship having a small conductor on another mast at a distance from it, on the principles already explained (45). Amongst the statements alluded to, were the cases of His Majesty's ships *Kent* and *Perseverance*, said to have been the only ships in a fleet damaged by lightning, and to have been the only ships having lightning conductors. See *Mech. Magazine*, vol. viii. pp. 13 and 287.

A TABLE showing the Number of Her Majesty's Ships known to have been struck and damaged by Lightning in various parts of the World between the years 1829 *and* 1842; *and the Number of Ships fitted with Pointed Conductors fixed in all their Masts, employed on the same Stations in the course of the same period.*

STATION.	Ships not fitted with fixed Conductors, and damaged.	Ships fitted with fixed Conductors in all their Masts, and not damaged.
Mediterranean.	Ocean, 80; Gloucester, 74, *Cephalonia;* Gloucester, 74, *Malta;* Mosquito, 10; Melville, 74; Madagascar, 46; Wasp, 18; Rodney, 92; Tyne, 28; Powerful, 84; Scorpion, 10; Blazer, steam-vessel; Ceylon, receiving ship; Tribune, 24.	Caledonia, 120; Asia, 84; Aigle, 24; Revenge, 76; Rodney*, 92.
East Indies.	Tamar, 26, Hyacinth, 18, *Penang;* Hyacinth, 18, *Indian Ocean;* Raleigh, 18; Endymion, 46; Starling, 4, surveying vessel; Harrier, 18.	Cornwallis, 74; Minden, 74; Agincourt, 74; Talbot, 28; Wolf, 18.
North America and West Indies.	Racehorse, 18; Racer, 16; Gannet, 18; Renard, 6; Snake, 16; Pique, 36; Royal Oak, receiving ship.	Blanche, 46; Forte, 44; Sapphire, 28; Tweed, 20; Scylla, 18; Orestes, 18; Resistance and Crocodile troop-ships.
South America.	Racer, 16.	Spartiate, 74; Malabar, 74; Dublin, 50; Druid, 46; Actæon, 28; Daphne, 18; Fly, 18; Beagle, 10; Bramble 10, surveying vessels.
Cape of Good Hope and Coast of Africa.	Medina, 20, struck twice; Columbine, 16; Lynx, 3; Pelican, 18; Primrose, 18; Atholl, 28; Buzzard, 3.	Southampton*, 52; Dryad, 42.
Channel and General Service.	Southampton, 50; Dispatch, 18; Pelican, 18; Rhadamanthus and Gorgon steam-frigates.	St. Vincent, 120; Wasp*, 18; Erebus and Thunder, surveying vessels.

* These ships are found in both columns, in consequence of their having been fitted with fixed pointed conductors, *after* they had been struck and damaged by lightning.

Whether Lightning Rods attract Lightning.

98. Amongst the objections made to the employment of lightning rods, there appears to have been none so popular, and at the same time so plausible, as this, viz., that by setting up pointed conductors we invite lightning to our buildings, which otherwise would not fall on them; that should the quantity of electricity discharged be greater than the rod can carry off, the redundant quantity must necessarily act with destructive violence; and that since we can never know the quantity of electricity which may be accumulated in, and be discharged from, the clouds, it is not improbable but that any conductor which we can conveniently apply, may be too small for the safe conveyance of such a charge.

Although the advocates of these opinions have never adduced any substantial fact, or any known law of electricity, in support of them; although they have never, by any appeal to experience, shown that buildings armed with lightning rods have been struck by lightning more frequently than buildings not so armed, nor demonstrated any single instance in which an efficient lightning rod, properly applied, has failed to afford protection,—nevertheless such views have been commonly entertained: indeed so strenuously have they been insisted on, and that too by persons of education and influence, that the Governor-general and Council of the Honourable the East India Company were led to order the lightning rods to be removed from their powder magazines and other public buildings, having in the year 1838 come to the conclusion, from certain representations of their scientific officers, that lightning rods were attended by more danger than advantage; in the teeth of which conclusion, a magazine at Dum Dum, and a corning-house at Mazagon, not having lightning rods, were struck by lightning and blown up*.

In a work on Canada, published so lately as the year 1829†, we find the following passage: "Science has every cause to dread the thunder rods of Franklin: they attract destruction, and houses are safer without than with them. Were they able to carry off the fluid they have the means of attracting, then there could be no danger, but this they are by no means able to do." Assertions such as these, appealing as they do to the fears of mankind, rather than to their dispassionate and sober judgment, have not altogether failed in obtaining that sort of temporary favour which so frequently attends a popular prejudice, promulgated without reason, and received without proof. Not only is the idea that a lightning rod invites lightning unsupported by any fact, but it is absolutely at variance with the whole course of experience.

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* Correspondence with the Honourable Board of Directors; Professor Daniell and Dr. O'Shaughnessy.

† *Three Years in Canada.* By F. Mc Taggart, Civil Engineer in the service of the British Government.

99. The notion that a lightning rod is a positive evil, appears to have arisen entirely out of assumptions, and a partial consideration of facts. Thus in consequence of the track of a discharge of lightning being always determined through a certain line or lines, which upon the whole least resist its progress (48), it has often been found to fall in the direction of pointed metallic bodies, such as vanes, vane spindles, iron bars, knives, &c. The instances in which these bodies seem to have determined the course of lightning have been carefully recorded, the phenomena being peculiarly striking and remarkable (54); but on the other hand, no attention has been given to those instances in which lightning has altogether avoided such bodies, and passed in other directions (46). Now it will be found, as we shall presently show, that the action of a pointed conductor is purely passive. It is rather the patient than the agent; and such conductors can no more be said to attract or invite a discharge of lightning, than a water course can be said to attract the water which flows through it at the time of heavy rain.

We have shown, in a former section (71), what quantity of metal is really sufficient for the perfect conduction of any quantity of lightning liable to be discharged in the most severe thunderstorms: therefore, to assume that any conductor which may be applied is not sufficiently capacious, is to reason against experience, and to resort to a species of argument quite foreign to the conditions of the case. It would be, as if we were to insist upon the danger of applying water pipes to buildings, under the assumption that we do not really know what quantity of rain may possibly fall from the clouds, and that hence the pipe may after all be too small to convey it.

In all these reasonings we should recollect, as already explained (10), that the forces in operation are distributed over a great extent of surface, and that the point or points upon which lightning strikes is dependent on some peculiar condition of the intervening air, and the amount of force in operation,—not on the mere presence of a metallic body projecting for a comparatively short distance into the atmosphere,—"that such bodies provoke the shaft of heaven is the suggestion of superstition, rather than of science*."

We shall now leave the theoretical discussion of this question, and direct attention to the facts themselves, and examine how far the evidence deducible from such facts is conclusive upon this important point.

100. During the thunderstorm which spread over the neighbourhood of Plymouth, in May, 1841, the electrical discharge struck one of the high chimneys at the Victualling-Yard, as already mentioned (94); it fell also on the topmast of the sheer-hulk

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* LESLIE, *Edin. Phil. Magazine.*

off the Dock-yard, about a mile and a half distant. Now the circumstances attendant on these discharges of lightning bear directly on the question before us. The chimney at the Victualling Yard is a round column of granite, about one hundred and twenty feet high, attached to the bakehouse; it *has not a particle of metal in its construction, nor has it any projecting point.* It stands at a distance of about one hundred yards from a clock-tower in the same yard; which, on the contrary, *has* not only a metal vane, and cross-pieces of metal, indicating the four cardinal points, but its dome is covered with copper, and there is a large conductor continued partly within and partly without the tower, from the dome to the ground. In the sheer-hulk a very small metallic wire was led along the pole topmast, and connected with the large metallic chains attached to the mast and sheers: the height of this pole was comparatively low, and it was completely overtopped by the neighbouring spars of the line-of-battle ship *Cornwallis*, fully rigged, and fitted with conductors on each of her masts. Now when the disruptive discharges took place, they fell on the granite tower, which had not a single metallic substance in its construction, and on the low flag-staff pole of the sheer-hulk's mast, notwithstanding that the clock-tower near the chimney offered every possible "invitation" to the discharge, and the great altitude of the line-of-battle ship's spars were in the most favourable position for "attracting" the electrical explosion. The chimney was rent for sixty feet; the flag-staff of the hulk's mast was slightly injured, and the small wire broken and fused; the lower mast and chains were uninjured.

On the 25th of March, 1840, Her Majesty's ships *Powerful* and *Asia*, each of eighty-four guns, were at anchor within a short distance of each other in Vourla Bay, in the Mediterranean. The *Asia* had the fixed pointed conductors already described (84) attached to each of her masts; the *Powerful* was unprovided with any lightning conductor whatever. Under these conditions they were both exposed to a severe thunderstorm. A discharge of lightning fell on the *Powerful*, the ship without conductors, and shivered some of her spars; whilst the *Asia*, where every supposed "invitation" to the discharge was most prominent, experienced no ill effect.

If no other cases were on record, these alone, would be sufficient to dispel all apprehensions of a metallic conductor "attracting or inviting" lightning. A great number of instances, however, equally clear and satisfactory, exist; from these we have selected the following:—

Amongst some interesting remarks on the effects of lightning, by Professor Winthrop, communicated by Dr. Franklin to Mr. Henley, it is stated, that a tree, which stood at the distance of fifty-two feet only from a pointed conductor attached to a house, was struck by lightning and shivered, while the conductor and house escaped*,—that is to say, the lightning fell on a body, which, according to the prevalent notion, had little or no attraction for it, and held out no "invitation," in preference to one which did,—a fact totally at variance with the whole assumption.

We have already adverted to the case of the *Southampton* (46), in which a heavy electrical discharge fell upon the sea close to the ship, during a thunderstorm on the east coast of Africa. But what makes this case especially applicable to the question now under consideration, is the circumstance, that all her masts were fitted with fixed lightning conductors, which terminated in copper spikes. The storm was awful, and is stated by Mr. Martin, the master, to have lasted from ten P.M. to two A.M. "The night was pitchy dark, from the density of the surrounding clouds: the roar of the thunder was incessant, and the flashes of lightning frequently so vivid, as to affect the sight for some minutes," yet no ill effect was experienced; the electrical discharge was not drawn down in an explosive form exclusively upon the conductors, although it actually fell with violence upon the sea close to the vessel.

Similar effects were observed in His Majesty's ship *Sapphire*, armed with pointed conductors of the same kind. Captain Wellesley, who commanded this ship, states that "the lightning was so vivid, and the flashes so quick in succession all around the ship, that although the duty to be done was important, I hesitated to expose the crew to them*; yet the ship was not struck." In another place he states, "that the *Sapphire* often met with very severe lightning, but it was never attracted to her†."

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* *Phil. Trans.* vol. LXIV., p. 152.

The frequent instances in which lightning avoids the most prominent parts of buildings, and falls obliquely upon some point far removed from them, may be further adduced as evidence against the attractive influence of such projections. The long zig-zag track of lightning, arising from the resistance of the air to its more direct path, may cause it to fall very obliquely on the earth's surface, as is well known: indeed, some of the directions of the zig-zag, may become almost horizontal. Now, in these cases, the pointed extremities of a tower, or the masts of ships, have no influence whatever on the course of the explosion; which, on the principles already explained (45), finds its way through the least resisting interval. Mr. Alexander Small states, in a letter to Dr. Franklin, that he saw an explosion of lightning pass before his window in a direction nearly horizontal, and strike a clock-tower far beneath its summit.

In the discharge of lightning, which fell on His

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* They were afraid to hoist the boats out.

† *Report of Commission on Shipwreck by Lightning.*

Majesty's ship *Opossum* in the English Channel, in March, 1825, "a peal of thunder burst on the main rigging, and split the top-mast cap*." Her Majesty's ship *Pique* was struck by lightning in the St. Lawrence, in November, 1839, by a discharge which fell on the fore-mast just beneath the head of it, and from thence passing down the mast, did considerable damage. Such cases, although comparatively rare, and to a certain extent exceptions to the general course of lightning, are still sufficient to show how little the direction of electrical explosions is determined by the influence of points *considered as mere attractors*, and that it is only when they can contribute to the equalization of the opposite electrical forces, that lightning strikes on them. Franklin, in endeavouring to draw off the electricity of a charged sphere by means of a pointed wire, found that the point when placed on a rod of glass or wax, had no action on it†.

When this large mass of evidence is duly considered, together with the fact, that lightning strikes indiscriminately, trees, rocks, and buildings, and even the ground near them, we are compelled to admit that the thunder-rods of Franklin are perfectly precise in their operation, and that the common notion, that they "invite destruction" to our buildings, is not warranted by any sound argument drawn from experience.

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* Ship's log.

† FRANKLIN'S *Letters*, p. 56.

It may not be unimportant to notice here the following extract from the *Memoirs of the Count de Forbin*, already alluded to (15). In describing the large St. Helmo's fires, observed in the vane of the main-mast, he says, "I ordered one of the sailors to take it (the vane) down; but scarcely had he taken the vane from its place, when the fire fixed itself on the head of the main-mast, from which it was impossible to remove it*;" so that the presence of the metallic point was not at all necessary to the electrical discharge.

101. Before quitting the subject of the absolute protection from lightning afforded by conductors, the Naval Commission inquire, whether, according to the common prejudice, conductors have the power of *attracting* a flash of lightning, which in their absence would not have occurred; and their report states "that the instances of accidents to ships *without conductors*, and the comparatively rare occurrence of lightning being observed to *strike* on a conductor, would tend to negative such a supposition†." They further consider, from the instances which were submitted to them, of ships without conductors having been struck by lightning, in the presence of ships furnished with them, which were not so struck, that most complete evidence is afforded "either of the little influence exerted by

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* *Letters on Electricity.* By the Abbé Nollet.—Vide *Phil. Trans. for* 1753, p. 201.

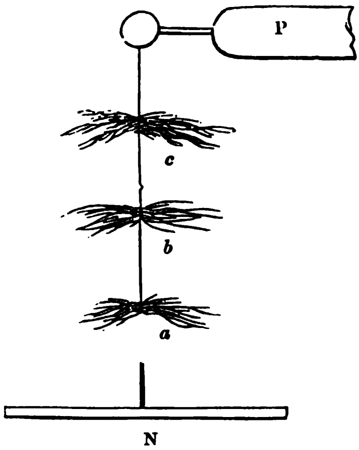
† *Report of Commission*, p. 4.

such conductors in inducing or attracting an explosive discharge, or of their efficacy in harmlessly and imperceptibly conveying away electricity to the water*."

Whether in certain cases pointed Conductors actually prevent Explosions of Lightning from falling on Buildings. The Phenomena observed when a concentrated Discharge strikes upon a Conductor.

102. Amongst the early discoveries of Franklin, we find the following curious experiment. A very fine lock of cotton *c* Fig. 45, was connected with the conductor P, of an electrical machine, by a thin thread, spun out of the same lock; under this was attached in a similar way another lock *b*, and to this a third lock *a*. On turning the machine, these

Fig. 45.



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* *Report of Commission*, p. 4.

locks of cotton began to spread forth their fine filaments in various directions, and to extend themselves towards the table at N, much in the same way that the petty fragments on the lower surface of a thunder-cloud lean towards the earth. On presenting a sharp point at N to the lowest lock *a*, it immediately shrunk back upon the lock *b*, and this again upon *c*, and all together upon the conductor P, where the locks remained as long as the point N continued under them*.

From this ingenious and elegant experiment, Dr. Franklin inferred, that the small ragged fragments extending from the under surfaces of thunder-clouds may by a pointed conductor be soneutralized or robbed of their charge, as to shrink back upon the main body. By this action, therefore, not only is the distance of the thunder-cloud increased, but the amount of the whole electrical disturbance (10) greatly reduced; thus obviating the concentrated explosion which, by the extension of the general mass toward the earth, would probably ensue.

The following experiment, which is new of its kind, furnishes both a pleasing and useful illustration of this action of pointed conductors: *c p b*, Fig. 46, is a long bent arm of light brass wire, balanced by means of central point *p* on the charging-rod of the jar J, and on which it has free motion in all directions; A is a light disc of gilded wood, resembling a common scalepan, covered with a lock of fine cotton wool, and suspended by conducting threads

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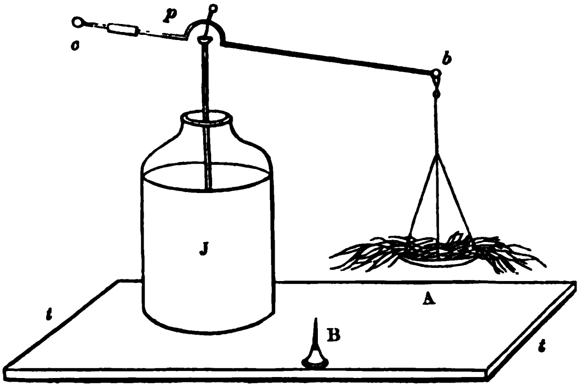
* FRANKLIN'S *Letters*, p. 121.

Fig. 46



from the arm *c b p*. A pointed body B is placed on the same conducting base *t t* with the jar. If the jar be now charged, the cotton in the scale-pan will begin to extend its filaments, and the whole will be attracted toward the table, much in the same way as a cloud appears to be attracted toward the earth, causing the bent arm *c p b* to assume an inclined position. If the arm be now caused to move upon its centre *p*, so as to allow the artificial cloud A to approach the point B, the arm will gradually assume its previous horizontal position, in consequence of the influence of the point in neutralizing the opposite forces. As the artificial cloud continues to approach the point, this action proceeds so rapidly, as frequently to produce a whizzing sound, the bent arm recovering at the same time its horizonal position, the scale-pan A, so far from being attracted by the point, actually recedes from it, and very faithfully represents the kind of operation of pointed bodies on charged clouds, viz., their power of discharging the electricity of the clouds without attracting them.

When the distances and charge are nicely adjusted, this experiment is very striking and satisfactory.

Mr. Wilcke, who made some very acute remarks on Franklin's views of electricity, states, that he witnessed the result of this action of pointed bodies on the great scale of nature in August, 1758. A large fringed cloud, strongly electrified, and extending its inferior surface towards the earth, suddenly lost its electrical character, in passing over a forest of tall fir trees. The ragged and depending portions shrank back upon the main cloud, and rose up as it were from the earth*.

The great number of cases we have cited (92) (98), with a view of showing, not only the protecting effect of lightning rods, but their passive character as attractors of lightning, may be further adduced in illustration of this peculiar property of pointed conductors. Indeed, it is almost impossible, to account for the fact of so many buildings being repeatedly struck by lightning, before they were furnished with lightning rods, and so seldom struck afterwards, and that lightning has seldom, if ever, been observed to fall in an explosive form upon buildings involving pointed metallic conductors in their construction,—without admitting, that the conductors had rapidly neutralized the electrical state of the air, and so prevented the occurrence of a dense explosion.

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* FRANKLIN'S *Letters*, p. 351.

We find this effect especially apparent (92) (93) in the case of the tower of St. Mark at Venice, the chapel of the Count Orsini, the temple of Jerusalem, the monument of London, the cathedral at Geneva, and many others; and if we add to these, the remarkable instances of certain ships of the British navy, enveloped as it were in violent thunderstorms in tropical climates (97), without any dense explosion falling on them, the evidence of this action of pointed conductors, in mitigating the fury of electrical discharges, is as complete as any evidence from experience can be imagined.

Phenomena observed when a dense Explosion of Electricity falls on a Lightning Rod.

103. Instances in which the forces have not been so rapidly neutralized by the action of pointed bodies, as to prevent some portion of the discharge from falling upon the conductor in a concentrated form, are by no means common: when they do occur, however, the explosive action subsides in striking on the point. The phenomena in such cases correspond accurately with those of artificial electricity, and are of a highly interesting character. The crash of the thunder is attended by a loud whizzing sound, described by some observers as the

rushing of water, or like the sound heard on lifting the valve of a steam boiler; at the same time the conductor becomes covered with a luminous glow or streak of light, and appears at the part struck to be enveloped in electrical fire.

The luminous appearance was observed at an early period of the application of lightning rods. When the heavy discharge fell upon the tower at Sienna in 1777, several persons noticed upon the conductor a long and regular train of light*. At the time of the dense electrical explosions which fell upon Her Majesty's ships *Druid*, *Beagle*, *Dryad*, &c. (96), the observers all agree in representing the discharge as attended by a loud whizzing sound, and upon the conductors a transient glow of light.

104. These phenomena are easily produced by artificial means. If we attempt to discharge a highly charged jar through a pointed rod, a loud whizzing noise, in the direction of the point, will be heard, immediately before the dense explosion takes place. The production of the light is not so easily accounted for; but the results of scientific inquiry favour the opinion that it is a sort of glow, between metal and air immediately in the points of contact; that it is of a perfectly harmless nature, and may be classed with the phosphorescent flashes attendant on the aurora borealis, or with the

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* TILLOCH'S *Mag.*, viii. p. 318.

streaming of ordinary electricity in the exhausted receiver of an air-pump. It may be produced artificially on a conducting wire, either by increasing the electrical charge in respect of the size of the wire, or diminishing the atmospheric pressure.

Harmless Character of the luminous Appearances observed on Lightning Rods.

It is essential to distinguish between this glow on the surface of lightning rods, and the heat evolved by the passing shock. We have already shown (71) that no mass of metal, equal in conducting power to a copper rod half an inch in diameter and two feet in length, has ever been fused or even sensibly heated by lightning*; and it is well known that any quantity of electricity may be discharged through a conducting rod, even whilst in contact with the most inflammable compounds, such as gunpowder, &c., without igniting them, provided the temperature of the rod be not considerably increased by the discharge. If the atmospheric pressure about such a wire be diminished, we immediately observe it covered at the instant of the discharge, with a luminous glow, yet it is not sensibly heated, nor will inflammable matter in contact with it be inflamed.

There are many interesting examples on record, of the small degree of heat of this species of electrical action. The St. Helmo's fires, and other electrical lights which so often settle on the masts and ropes of ships, are unattended by any calorific effect; and persons during electrical storms, have appeared to be enveloped in weak flames, without being at the time in any way conscious of it.

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* *Shipwreck by Lightning*, *Report and Evidence*, p. 13.

A remarkable instance of the harmless nature of these appearances was observed by Ross and Sabine, in returning from their last Arctic expedition. In the Greenland seas, during a dark cloudy night, they observed a sort of glow discharge on the surface of the water, directly in the ship's course. It appeared to occupy a space of four or five hundred yards, and had very considerable elevation. The vessel at length sailed out of a pitchy darkness, directly into this luminous mass; all at once the masts, yards, and sails, as the successive masts passed forward, became covered with light. The ship having sailed completely through it, became again involved in profound obscurity*.

This was evidently one of those glow discharges, already explained (26). The deep black clouds covering the sky, being particularly indicative of that peculiar condition of the atmosphere observed in thunderstorms (34): as evidence of the small heating effect of this species of electrical light, the result is very important and conclusive.

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* Communication from Dr. Robison to Mons. Arago.—*Annuaire* for 1838, p. 372.

Lateral Discharge.

105. The phenomenon, termed lateral discharge in electricity, has frequently engaged the attention of electricians. So long since as the year 1780, Priestley found that a metallic rod (*n b*, fig. 9), (22), would, at the instant of discharging an electrical jar, emit a spark. At a more recent period, Professor Henry, of New York, in following up Van Marum's experiments upon small wires exposed to a current from the electrical machine*, obtained many new and curious results; he showed that sparks might be obtained from such wires, of an intensity sufficient to inflame hydrogen, and produce other powerful effects.

These results have been classed under the general head of lateral discharges, and have been adduced by many writers, without any very profound investigation of the subject, as a ground of objection to the employment of lightning rods. They have neither identified the phenomena with the conditions of electrical discharges from the atmosphere, nor have they brought forward a single case in which lightning rods, in the act of transmitting discharges of lightning, have thrown out such lateral explosions, and thereby caused damage to surrounding bodies: so that the conclusion arrived at, that lightning rods are likely to damage buildings by a lateral discharge of electricity, rests on no higher authority than that of a mere assumption.

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* TILLOCH'S *Magazine and Reports of British Association*, vol. vi.

It may be here observed, that if lightning rods are liable to produce lateral explosions upon surrounding bodies, so as to set fire to inflammable matter, and cause other destructive effects; then there is not a powder magazine in Europe, armed with such rods, which, upon being struck by lightning, would not either be blown up or damaged; but this at least we have shown (92) has never been the case.

106. Nevertheless, to avoid any resemblance of slighting, or slurring over this question, we will briefly discuss the facts on which it rests.

We have shown, (11) (13) that the very existence of all electrical discharge depends upon the neutralization of two opposite forces in some given direction, and that unless these forces can become neutralized, no discharge will occur, whether metallic bodies be present or not (100). Now it is to be observed, that in a charged electrical jar (fig. 9*), the force on the charged side P, is, from the process of charging, and from the induction of surrounding bodies (11), necessarily in excess of the force developed in the opposite coating N (12); that is to say, *all* the inductive action is not exerted between the coatings P N of the jar. When, therefore, we discharge the jar, we only neutralize that part of the charge existing between its coatings; the rest is left as it were behind, under the influence of surrounding bodies. But the coating N, being by the discharge rendered neutral, and being nearer the coating P than any other substance, the action of the remaining electricity becomes as it were called off from these distant bodies, and again operating by induction upon the neutral coating N, completes what may be termed a secondary charge. In this process it is evident electricity becomes again displaced from the neutral coating and other bodies connected with it, without which the opposite force could not be developed (11, fig. 4); so that if the whole apparatus be insulated on a glass stand, we may deal with it as with any other source of redundant electricity; that is to say, we may obtain it under the form of a spark thrown off by a charged conductor. Even this insulation is not absolutely necessary, provided we apply a free conducting substance to the discharging rod *n b*, or any body connected with the exterior coating N, before the electricity, rendered active by induction, has time to escape.

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* See page 29.

Biot examined this species of electrical action, and came to the conclusion that the spark observed to take place from the discharging circuit of an electrical jar, (22) is due to a small quantity of redundant electricity which always exists on one or other of its coatings, and not to the discharge.

Priestley, so long since as the year 1770, had arrived at nearly the same conclusion*, and in the *London and Edinburgh Journal of Science*, for December, 1829, will be found a further investigation of this subject by the author. It is there proved,—

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* *Phil. Trans.*, vol. LX., p. 192.

First, That at the time of the discharge, no portion of the neutralizing forces escapes from the discharging rod under the form of a lateral explosion.

Secondly, That the spark, supposed to be a lateral discharge produced by the passing shock, is as readily obtained *after the system has become neutralized*, as at the apparent moment of discharge.

Thirdly, That the kind of electricity of which the spark consists (12), varies with the electricity in excess upon either of the coatings.

Fourthly, That the magnitude of the spark varies with the extent of surface upon which the accumulation has taken place; so that a given quantity of electricity accumulated on several jars, does not produce a residuary spark equal to that obtained from the same quantity accumulated on one jar only, notwithstanding the heating effect of the accumulation remains in both cases the same; and further, that double or treble the quantity of electricity discharged from double or treble the number of equal jars, gives a residuary spark of no greater magnitude than a single quantity discharged from a single jar; and that, as a double or treble quantity of electricity, in passing through a discharging rod, would certainly give out a spark of greater intensity than a single quantity, were this spark a lateral explosion, it is evident that the phenomenon termed lateral discharge is not referrible to any action of either of the neutralizing forces in their passage through the rod.

"I never observed," says Priestley, "the least attraction of bodies towards the brass rod through which the explosion passed, though I employed several methods which could not fail to show it. I could not find that the explosion of a battery, made ever so near a brass rod, ever disturbed its electrical state, for when I insulated the rod, and hung a pair of pith balls on the end opposite to that near which the explosion passed, I found the balls were not the least moved*." The application of this phenomenon, therefore, termed the lateral explosion, to the case of a lightning rod, is not warranted by the simplest experiments.

107. The small discharges thrown off by a wire leading from a ball in the act of receiving dense sparks from an electrical machine, result from the same species of action; the electricity accumulated on the conductor operates by induction upon surrounding bodies, but more particularly the nearest. Any secondary conducting substance, therefore, opposed to it completes the terminating surface of a charged system (11), so that the air between the opposed surfaces becomes charged. But in this process electricity is displaced from the wire by induction, and will strike off, as in the former case, on free conducting bodies, and this will continue so long as sparks pass between the two conductors,—that is, so long as a succession of charges and discharges continue. It is doubtful whether there really be a current discharge in this wire at all: its

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* Priestley's *History of Electricity*, p. 683.

condition is altogether dissimilar to that of a lightning rod. Besides these, there are many other circumstances, contingent on this experiment which greatly complicate the question; for since the great conductor of the machine operates by induction upon the table, floor, and walls of the room in which the experiment is performed, we may elicit sparks from gas pipes and wires leading to the earth, although in no way connected with the receiving ball. The nature of these sparks, will depend on the negative or positive induction on the floor, or other surfaces, by the positive or negative conductors of the machine. If the small wire from which the lateral explosions, as they are termed, proceed, be connected directly with the machine, these phenomena disappear; for the accumulation on the conductor, is prevented from reaching any great intensity—hence, in order to obtain this species of electrical discharge in any force, it is requisite to employ disruptive discharges between opposed conductors, and the larger the surface of the charged conductor, the greater is the effect produced.

108. It has, however, been contended, that although no lateral explosion should occur from the passage of the neutralizing forces (106), yet that the great excess of electricity in the charged cloud may produce it: "because, if the flash brings down only enough to compensate the induced condition of the earth, as it exists before the discharge, it will bring down more than the earth, in its then condi-

tion, has a capacity for*." All this, however, is extremely hypothetical: we have seen why it is that any excess remains, after the discharge of an electrical jar,—it is simply, because other bodies share in the induction, and all the force is not exerted between the coatings (106); but inasmuch as this condition does not apply to the clouds and earth (10), it is very possible that the forces between these, may *exactly* compensate each other without any remainder: hence, it is by no means proved that after an atmospheric discharge, the excess in question would exist, at least not to any extent, and if it did, it remains to be shown, that it could discharge upon a body, not having a "capacity for it," that is, upon a body in which an equivalent opposite state could not be induced. To imagine this, is to cast aside all the known laws of electrical charge: if, therefore, such an excess remain, it can only operate by a secondary discharge in a way perfectly analogous to the preceding, that is, by inducing a secondary disturbance; but this it could perhaps as well effect at first, and leave no remainder. Hence there would be either no excess of electricity in the clouds after an atmospheric discharge, or otherwise, if it existed, it would remain there until it induced in some other point of the earth's surface an opposite force (11), equivalent to produce disruptive discharge (13). That no redundant electricity passes over at the moment of discharge is quite demonstrable; for if a charged jar be placed on an insulated conducting base, and be discharged by a curved rod held by a glass handle, cautiously brought up from the outer coating to within a striking distance, then, although a considerable excess remains in the jar, not any excess will be found on the conducting table, if the jar be removed from the table by its insulating interval, without touching the outer coating.

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* *Proceedings of the London Electrical Society*, December 20, 1842.

109. The truth or fallacy, however, of particular views of this kind, is after all best appreciated by a careful examination of the laws of electrical discharge, observable in great natural operations.

We have seen (10) (45), that a lightning rod is a discharging conductor placed immediately between the terminating planes of a charged system, in which all the surrounding bodies are similarly involved; but this is not the condition of a wire placed beyond the system, where it in no degree contributes to the neutralization of the opposed electrical forces. Consequently we find, on appealing to the experience of nearly a century, that not a single case can be adduced in which a lightning rod, in the act of transmitting a heavy charge of lightning, has thrown off a lateral explosion on semi-insulated masses near it; and we shall now proceed to detail some facts, which will at once overturn the whole assumption.

In the account (51) of the damage done to St. Martin's church, in London, in July, 1842, we find the discharge to have been determined through a wire rod connecting the clockworks with the dials, leaving traces of fusion in the joints of the wire, but not, in the slightest degree, affecting its casing of wood by lateral explosion, *although the rod passed within ten inches of the large masses of metal in the bells.*

In every instance in which lightning has fallen on the iron vane rods of church spires, it has been safely conducted by these rods through a great length of solid stones, without any lateral discharge. In the case of the discharge which fell, in August, 1841, on the spires of St. Michael's and St. Martin's churches in Liverpool, no damage whatever occurred above the termination of the vane rods, although the rods passed through solid blocks of stone which formed the apex of the spires*, as represented in fig. 20†. The cases of St. Martin's and St. Bride's spires in London (51) (54), Kingsbridge church, in Devonshire (71), and many others, all confirm this important result.

The electrical explosion which passed down the chain conductor of Her Majesty's ship *Dublin* (80) fig. 32, and by which it was disjointed and partially melted, did not in any degree injure, by a lateral explosion, the small rope (fig. 34) to which the chain was attached, nor were there any lateral discharges thrown out upon the various metallic substances near which the conductor passed.

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* Communication from Mr. C. J. Smith, of Liverpool, who examined the spires.

† See Frontispiece.

In the numerous instances in which lightning has been discharged into the sea by the bolts in the solid timbers and planking of ships, we do not find any trace of a lateral discharge; although in large ships these bolts are several feet in length. Soon after the terrible shock of lightning had fallen upon the *Chichester* (87), Captain Stewart thought it necessary to haul the vessel up. "I examined," says he, "the planks about the bolts, and found all quite firm and watertight." In all the cases (96) in which dense explosions have been transmitted by conductors fixed to the masts of ships, no lateral discharge has occurred; yet they are very near a succession of metallic bodies,—viz., sheaves and pins, funnel for rigging, iron-bound caps, eye-bolts, chain slings, mast hoops, and even the great masses of the chain cables and water tanks.

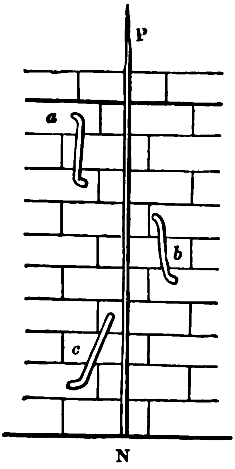
Division of the Charge.

110. Although there is no instance on record of an isolated lateral explosion of electricity from a lightning rod, yet we find instances in which the discharge has divided between the conductor, and other metallic bodies in connexion with the earth. As these cases have been also called "lateral discharges," it will be requisite to examine them. But before we proceed to the consideration of such cases, it may be as well to define clearly the

difference between a division of the passing shock upon other lines of conduction near the conductor, and a mere explosion of electricity. This is the more necessary, because those who have written on the subject, have never explicitly stated, what they really mean by *lateral discharge*, as applicable to the action of a lightning rod.

Let P N (fig. 46) represent a lightning rod, and *a b c* detached metallic masses, employed in the construction of a building, such as cramps or other fastenings, and near which the rod passes. Then, in the absence of the rod, these metallic bodies *a b c* are in a position to operate as so many stepping-stones for the electrical explosion, by which its course would be facilitated from the highest points of the building to the earth (49). Now, directly

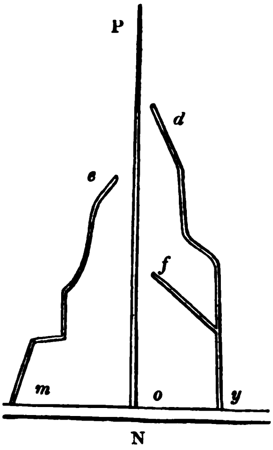
Fig. 46.



we apply the rod P N, we supersede the action of these masses, as so many points in a possible line of discharge (58), and prevent the damage which we have shown (94), would necessarily ensue between them. The only question, therefore, remaining for our consideration in such case is this, —can the bodies, *a b c*, elicit from the conductor P N, at the instant of its transmitting a heavy discharge of lightning, a destructive lateral explosion upon the parts of the building in which they happen to be placed. This is the legitimate and fair definition of lateral discharge as applicable to a lightning rod; and we have proved, both by a copious induction of facts, and by an appeal to experiment, that there is no such effect produced in the progress of either natural or artificial disruptive discharge.

The possibility of the discharge dividing in its course, between the rod and metallic bodies in good conducting connexion with the earth, is quite another question. Thus, let *e m*, *d y*, *f y*, (fig. 47), be metallic pipes or other conducting substances, terminating either directly, or indirectly in the earth at N, in common with the lightning rod P N. And suppose these substances to commence from, or to be continued through, some points *d e f* very near the rod; then, if from the small capacity of the rod, or any other casualty, the resistance in the direction of these points *d e f*, should happen to be less, or even equal to that in the direction of the rod P N, the charge, as already shown (47), is almost certain to divide upon the additional circuits, *d e f.* Hence it is that lightning rods should be united to all the metallic circuits in a building which lead to the ground, in order that all chance of destructive explosion between the conductor, and such circuits, may be avoided.

Fig. 47.



Arago, in his valuable "*Notices sur le Tonnerre*," published in the *Annuaire* of 1838, has quoted an instructive case of this nature*. It appears that for the protection of a house in the United States of America, a lightning conductor had been applied on the outside of the building, similar to that represented in the annexed figure (48), in which P is a pointed bar of iron projecting from the roof, N, a similar bar driven into the ground, and P *t* a small brass wire connecting the bars. At the point *n*,

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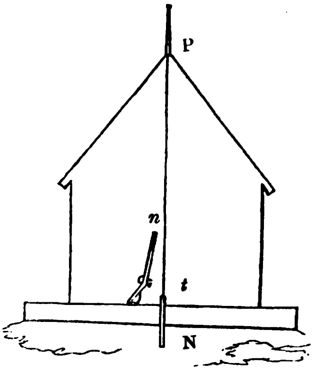
* Franklin's *Works*, vol. i., p. 361.

Fig. 48.



inside the house, stood a fowling-piece, *n*, with its barrel against the wall, and separated from the conductor P N only by the thickness of the masonry. In this arrangement, therefore, we have all the conditions specified in fig. 47; the consequence was, that when a discharge of lightning fell on the conductor at P, and passed on the small wire P *t*, it divided at the point *n*, upon the two circuits, and in doing this broke out a large hole in the wall of the house, and shattered the stock of the gun in forcing a passage to the earth. The small wire P *t* was completely melted so far as the point *n*, but not beyond it; the resistance in the direction P *t* N, at the point of fusion of the wire, evidently exceeded or was equal to the resistance in the direction P *n* N; hence the metal in the fowling-piece evidently saved the remaining portion of the wire *n t*.

The cases quoted of the damage by lightning to the Hôtel des Invalides, at Paris (66), to the French frigate *La Junon* (82), as also the shock experienced by the two sailors in the French frigate *La Calypso* (82), are all instances of this division of the charge between the conductor and other lines of transit to the earth or sea. It is quite clear, that in these cases the resistance to the progress of the discharge through the small and very long ropes of wire, exceeded, or was at least equal to, the resistance in other directions; consequently, these instances are very similar to the preceding.

"I am not aware," says Faraday, in speaking of such cases, "of any phenomenon called lateral discharge, which is not a diversion of the primary current;" "all liability to a division of the main charge would decrease in proportion to the capacity of the primary conductor*."

Instances in which Buildings provided with pointed Conductors are said to have been damaged by Lightning.

111. Although several instances have occurred in which buildings having pointed lightning rods have been damaged by lightning, yet is it a singular fact, that they may all be quoted in illustration of the great advantage of such rods, in safely transmitting heavy electrical discharges from the atmosphere.

We have shown, by reference to a variety of cases, both the small influence of pointed conductors in attracting or causing explosions of lightning, and the liability of the discharge to break up, before reaching the earth, into two or more streams (100), (24). In the cases of damage by lightning said to have occurred, notwithstanding the presence of a pointed conductor, the electrical discharge has divided in the air, into two or more streams, previously to striking the building. One portion has commonly struck upon the conductor, and been carried off by it, whilst other portions have fallen on points far distant from the conductor.

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* *Report and Evidence on Shipwreck by Lightning*, pp. 34, 35.

The first instance claiming attention, is the case of the church of "Notre Dame de la Garde," at Genoa, struck and damaged by lightning on the 14th August, 1779, a lightning rod having been applied to it in the previous year.

The church stands on one of the highest hills in the neighbourhood of Genoa, and clouds are constantly hanging over it; the bell tower to which the conductor had been applied, was originally even with the façade, but in consequence of a subsequent enlargement of the church, and the erection of a porch, it was thrown far back. The lightning conductor commenced from a stout iron rod, tipped with a gilded copper point; this rod projected from the top of the bell-tower three feet into the air, and from its termination a stout iron bar was continued, and led out through a window over the roof of the church, and so on to the ground. Before the lightning struck the church, it bifurcated (24), one of the explosions fell on the conductor, split open the gilded copper point, and was conducted safely to the earth: the other explosion struck the porch at a distance from the conductor, descended into the church, and did some damage; several persons who were in a room over the porch felt a violent shock, many were thrown down, but not hurt.

This account has been obtained from the *Sammlungen zur Physik,* for 1782*: the writer states that the accident was attributed to the conductor, but he shows that if the conductor had not been there, much greater damage must have ensued, and thinks it is perfectly clear that the church was struck in two places,—first on the conductor; secondly, upon the unprotected porch. This case, therefore, does not furnish any argument against the employment of lightning rods, but rather shows their value, and points out the necessity of securing the portions of a building which are distant from the rod.

The case already alluded to (74), of the Boardhouse at the Purfleet magazines having been struck by lightning, in May, 1777, is another instance in which a building furnished with a lightning rod was damaged. From the description of this building, it will be seen that the corner struck was forty-six feet distant from the point of the conductor. Little or no damage was done: a few stones only were displaced. Now, there can be very little doubt but that the conductor really carried off safely and silently a great portion of the discharge; it is impossible to explain on any other principle how so small an amount of damage ensued from so heavy a discharge as this appears to have been, especially if we suppose it to have been concentrated upon two clamps on a corner of the building. The probability is, that the discharge bifurcated, as in the preceding case; and whilst one division rushed through the conductor, the other struck a distant point of the house. The clamps on which it fell, were fixed in the coping-stones of the parapet, and were about seven inches above the lead gutters of the roof, which constituted a portion of the general system of conduction to the ground (74).

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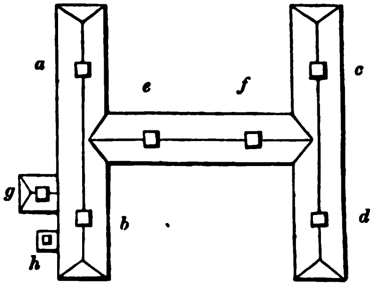
* Vol. ii., p. 588.

The discharge, in forcing its way through seven inches of bad conducting matter to the lead beneath, did some damage by an intermediate explosion, but it was very inconsiderable; had the iron clamps been continued to the general mass of metal on the roof, it is quite certain that no damage whatever would have occurred.

The case of the Heckingham poor-house (74), said to have been struck and damaged by lightning in June, 1787, although armed with eight pointed conductors, furnishes another remarkable instance of the protective power of lightning rods.

The general form of this building is represented in the annexed fig. 50. It consists of a centre range, *e f*, one hundred and eight feet in length, with two flanks, *a b* and *c d*, each about one hundred and sixty feet. It had eight chimneys at *a b c d e f g h*,

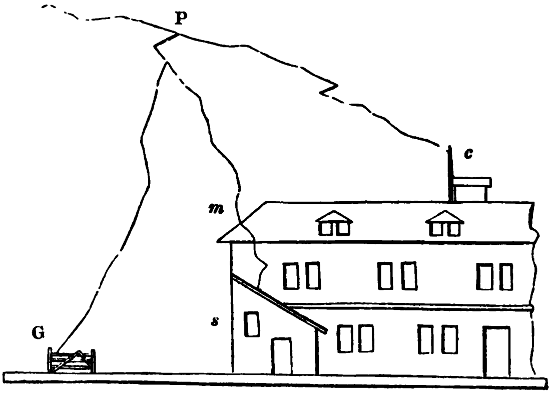
Fig. 50.



each furnished with a pointed iron rod, these rods communicated with each other, and were connected by four branches with the ground. The part of the building struck was one "hip of its extreme corner" at *m*, fig. 51, nearly seventy feet distant from the nearest conductor, *c*.

In the account given of this case in the *Transactions of the Royal Society*, it appears that an observer who witnessed the descent of the lightning, saw it

Fig. 51.



divide in some point, P, into "three fire-balls," as he termed them. One of these struck in the direction of the conductor at *c*, another damaged the corner of the building at *m*, together with a shed at *s*, and the third struck upon the ground in front of the house, near a gate, at G*.

This was evidently an instance of the trifurcation of lightning (24), one of the divergent branches or streams having fallen on the conductor. But this part of the explosion was discharged safely into the earth, whilst the shed *s*, and corner *m*, which were unprotected, suffered. This case, therefore, affords conclusive evidence of the value of lightning rods. The committee of the Royal Society, in a report on this circumstance, considered that the rods were not so "perfectly applied as they ought to have been;" they were, however, sufficiently well applied to meet any discharge of lightning likely to have fallen on them. No part of the building near them was damaged, and it is not to be expected that they should defend parts at a great distance (74), especially when such parts are the first exposed to an electrical cloud moving toward them, and likely to strike upon them obliquely (100).

The instance in which lightning fell upon a magazine of powder at Bayonne, in February, 1829, furnishes another remarkable illustration of the liability of the electrical discharge to divide in the air, and strike on a part of a building distant from a lightning rod, as well as on the rod itself. This case, which was reported on by the physical section of the Royal Academy of Sciences at Paris, gave rise to much interesting discussion.

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* *Phil. Trans.*, vol. LXXII., p. 377.

The building is about fifty-six feet in length, and about thirty-six feet wide: it is covered by thick vaulted masonry, and a sloping roof with gable ends; these were protected by plates of lead; the gutters also were of lead, and there were the usual appendages for discharging the rain.

The lightning rod projected about twenty feet above the building: it was attached to the lead of the roof by a metallic socket, through which it passed, and which was soldered to one of the lead coverings. Instead of being carried, however, directly into the earth at the foot of the wall, it was turned outward, at about two feet from the ground, and, being bent at right angles, was continued on semi-insulating posts of wood into a trench filled with charcoal, distant thirty-three feet from the wall.

On the 23rd of February, 1829, about 4 A.M., a discharge of lightning fell on this building. The point of the conductor was melted, and the plates of lead, by which it was attached to the wood posts at the foot of the wall, were more or less torn and perforated by holes. No damage, however, ensued to the building in the course of the conductor. At the south-west corner, a sheet of lead covering the gable end was torn out immediately over a point where two stones of the cornice were united by an iron cramp. Hence, as in the case of the magazine at Purfleet, this distant part of the building was also visited by an electrical explosion.

The reporters state, that the conductor, in consequence of being continued at so great a distance from the building, did not offer a sufficiently easy line of transit for the discharge to the earth, which is, they think, evident, from the damage to the wooden posts on which the conductor was supported: hence they infer, that the discharge divided between the conductor on which it first struck, and the metals of the roof, and that the small rent on the lead, on the south-west angle, was the result of this division, in a point through which the electrical discharge found its way; that this is the more probable from the circumstance of the rain having at this point beaten against the walls, and so increased the facility of conduction by means of a "sheet of water, to the ground*."

It is however very doubtful, whether any division of the charge really took place in this case. The circumstances being analogous to those stated in all the former instances, it may be inferred that here also the lightning struck on two points, viz., on the conductor, and on a point distant from the conductor; and that the trifling damage which occurred at the distant point, arose from the passage of the discharge through detached conducting matter to the earth. With respect to the conductor itself, it evidently did its duty, since no damage occurred in those parts of the building along which it passed; that the electrical discharge should endeavour to find the shortest road to the earth, through the posts of wood which supported it, rather than follow the conductor through a distance of thirty-three feet to an indifferent conducting termination, is only what might have been anticipated from all the known laws of electrical discharge, and which we have already illustrated (48), (50). Had a portion of the discharge really left the conductor, and divided upon the metals in the roof, some trace of it would certainly have been found at the point of division; which probably would have been where the spike of the conductor entered the socket of metal which connected it with the roof.

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* *Annales de Chimie*, tome XL., p. 391.

Indeed, it is quite impossible to conceive, the existence of the discharge in the conductor in such force, as to break away from the general line of conduction, without producing explosive effects immediately in the point of division; but nothing of this kind was found; in the points where the discharge passed into the ground, through the posts of wood, the lead was torn in various places. There is no instance on record of a division of the charge unattended by explosive effects at the point of its division upon other lines of conduction, in consequence of the insufficiency of the conductor.

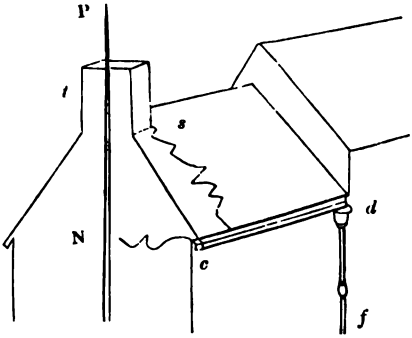
It is therefore highly probable, that in this, as in the preceding cases, the discharge bifurcated and fell on the building in two different places. But whichsoever of these explanations we may choose to admit, the result is by no means inimical to the application of lightning rods, since the damage was, after all, very inconsiderable, and the building was virtually defended by the conductor from the terrible consequences which we have seen (92) so often occur in other cases, in which powder magazines have been struck by lightning, without a similar means of transmitting it to the earth.

Messrs. David Rittenhouse and Francis Hopkinson relate, in the *Transactions of the American Philosophical Society*, a remarkable instance in which a house in New Chester, United States, furnished with two pointed conductors, was struck by lightning, and slightly damaged on the roof.

This house was situated on a rocky base, at the foot of a steep ascent, and within a few yards of a mill dam. The building was of stone, two stories high at the west end, on which the discharge fell, and three stories at the east end; the building had two stacks of chimnies rising from the roof: the conductors were fixed to one of the stacks at each end, and then passed directly down the outside of the wall, where they terminated in the rock. The situation of the west conductor, in respect of the chimney and near metallic matter, may be represented as in the annexed figure, in which P N represents the rod fixed to, and passing along the *west* face of the chimney;

s represents the southern face of the same chimney: *cd* is a water gutter, covered with copper, which

Fig 52.



runs along the roof from the west towards the east end, where it is connected with a copper spout passing down the wall to within four feet of a cistern resting on the ground, and into which it discharges the rain.

After the electrical discharge struck this building, a considerable portion of the extreme end of the conductor at P, was fused, and the ground at the foot of it torn up: hence it is quite clear that a large amount of the charge passed down the conductor. But in addition to this, the shingle of the roof was torn up on the south side of the chimney at *s*, directly down to the copper pipe *cd*; at the point *c* also, directly in the line of the cornice; slight damage occurred in the line N *c*, between the conductor and the pipe: hence the discharge also passed, in the directions N *c*, *s c*; and it remains, therefore, to explain how this occurred.

Now, in the first place, it is to be remarked, that the copper pipe, in passing nearly to the ground, in the direction *c d*, and ending near water, constituted a conducting path of as little resistance, as the rod of iron P N, ending in a dry rock. Hence this case would appear to come under the conditions of division of charge just explained (11); if so, it is highly illustrative of the necessity of applying lightning rods in such way, that the discharge, in striking a building, cannot possibly enter into any circuit of which they do not form a part; had the circuit *c d* been connected with the circuit P N, no damage could have arisen: this case, therefore, furnishes no argument against the employment of lightning rods, but only against their inefficient application.

But there are some facts connected with this case, which throw much doubt on the conclusion, that the electrical discharge, in passing down the rod, had really divided between the rod and the pipe. In the first place, if any portion of the discharge had left the rod, it would not have divided in two places; and it is inconsistent with the course of our experience of electrical discharge, to suppose that the explosion could have appeared on the south side of the chimneys, distant from the conductor, without intermediate damage between *t s*. For it is a well established fact, that the immediate point from, or upon which the electrical discharge explodes, is that in which the greatest damage occurs. The phenomena are equally well explained by supposing, that the lightning, on falling obliquely upon the west end of the house, had divided, one part on the conductor at P, the other on the south side of the chimney and roof at *s*. The portion which fell on the conductor was of course carried off by it: the portion which fell on the roof at *s*, took the line of the roof directly to the good conducting pipe, *c d*, and having reached this, passed off partly in the direction *c d f*, and partly in the direction *c* N, by means of the conductor. And this is rendered the more probable, as the distance of the pipe, *c d f*, from the cistern on the ground, was not far different from that of the distance of the pipe from the conductor *c* N, viz., from four to six feet: hence the resistances in these directions were nearly equal. This explanation does not involve any contradiction whatever, and it is quite consistent with the many examples we have quoted of the division of lightning, and of its striking upon points close to conductors (46).

The damage done in this case was, after all, very trifling, notwithstanding that the discharge, by the prodigious noise which is described as having attended it, and its effects on the conductor, must have been extremely violent; so that the case, upon the whole, fully confirms the value of the lightning rod.

The following well authenticated instances of recent occurrence, in which lightning has fallen upon bodies in the vicinity of conductors, as well as upon the conductor itself, are very similar to those just described, and they furnish satisfactory evidence of the nature of such cases.

Her Majesty's brig *Racer*, commanded by Captain J. Hope, was struck by lightning in May, 1835, in latitude 39° north, longitude 63° west; a chain conductor was up at the main-mast (80) fig. 32. The electrical discharge fell with destructive violence on the fore top-gallant mast, distant from the conductor about forty feet, at the same time sparks were seen on the chain, and a rustling noise was heard throughout its length* (96). We have here a remarkable illustration of the nature of the accident at Purfleet. The conductor evidently transmitted without explosion a great portion of the discharge, and consequently prevented the damage which must have ensued, had the whole been concentrated on a single unprotected point.

Dr. O'Shaughnessy relates the following instance of the bifurcation of lightning†, which, on examination, will be found to have a very forcible application to the case of the damage done to the magazine at Bayonne. It appears that, in May, 1837, an electrical explosion divided upon two adjoining houses in Chowringhee, East Indies; one of the houses not having a lightning rod, in the occupation of Dr. Goodeve, was struck and damaged, whilst the adjoining house, tenanted by Mr. Trower, and to which a lightning rod had been applied, escaped, although a portion of the explosion fell on it with great violence. "Dr. Goodeve, while walking in the verandah, saw the lightning strike Mr. Trower's conductor, and at the same time strike his own house." The distance of the damaged part of Dr. Goodeve's house from the conductor, appears, from a subsequent examination, to have been sixty-six feet, about the same distance as that in the case of the Heckingham poor-house, just described

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* Ship's log, with remarks by Captain J. Hope, R.N.

† Reports to the Honourable the Court of Directors of the East India Company.

This case, so remarkably conclusive as to the protecting effect of lightning rods, has nevertheless been adduced as an evidence of their liability to draw down greater discharges upon buildings than they can transmit, thus causing damage to surrounding bodies; we have, however, already shown (100), that pointed metallic rods have no such attractive influence, and that discharges of lightning are determined towards the earth by very different causes. But even if it were true, that a pointed metallic rod did invite or attract lightning towards it, still we cannot suppose it to attract more than it can conduct, since the attraction would entirely depend on the superior conducting power of metals: to assert, therefore, that a conductor can draw towards it more lightning than it can conduct, is to assert in other words that it attracts more than it can attract, which is evidently an absurd proposition.

The last instance which we have to notice of damage done by lightning to a building furnished with a conductor, is the case of the Melville Monument, in St. Andrew's Square, Edinburgh. The mode of application of the conductor has been already described (77); it consisted of a pointed metallic rod, which passed through the statue, and was connected with an iron chain led through a hollow way in the stair-case to the ground.

On the 14th of July, 1837, an electrical explosion fell on this building, by which the wooden door, leading from the staircase to the platform of the gallery, was forced off its hinges, and the stones at the top near the door were loosened. On examining the conductor after the accident, it appeared that the chain, connecting the pointed rod with the ground, had been, by accident or design, drawn up for some considerable distance through the hollow way in the staircase, and coiled round a stick placed across the top of the stone tube round which the stair was built. The stick was so placed as to press against the door leading to the platform, in order to keep it shut.

The damage in this case, therefore, did not arise from any failure in the principle on which the conductor was applied, but entirely in consequence of the displacement of its inferior portion, which reduced it to the condition of a semi-insulated mass of metal.

In so long a period as three-quarters of a century, it is not to be expected that no casualties should occur, either from a defective application of the conductor, or from an explosion falling on some part of the building at a distance from the conductor. But the few accidents on record can scarcely be urged as an objection to the general principle, especially when we take into consideration the great number of lightning rods set up in various parts of the world. In the United States alone, some thousands of lightning rods have been erected since the time of Franklin's great discovery; yet only two instances are quoted, in which damage occurred there, and these, as we have endeavoured to show, do not warrant any distrust of the principles on which such rods are applied.

Concluding Observations.

112. Upon a review of what has been advanced in the course of these pages, relative to the nature of thunderstorms and the operation of lightning rods, it appears, that buildings and other elevations are struck and damaged by lightning, only in consequence of their being points in one of the terminating planes of a great electrical disturbance in the atmosphere; not from any property of attraction for the matter of lightning, inherent in the substances of which such elevations are composed:—that lightning rods remove, by the aptness of their parts, the resistance experienced by the electrical discharge in moving through less perfect conducting matter; and hence, by allowing a rapid and free neutralization of the opposite electrical powers, they prevent the damage attendant on an obstructed action:—that the opera-

tion of such rods, being of a purely passive kind, they can no more be said to invite or draw down lightning upon the buildings to which they are applied, than a rain-pipe can be said to draw down or invite the rain which flows through it:—that such a passive property cannot be fairly adduced as an argument against their general use:—that since lightning rods only operate in transmitting as much electricity as falls on them, they cannot be prejudicial to buildings, but must, on the contrary, by a rapid annihilation either of the whole or part of the force in action, necessarily contribute to security:—that lightning, being nothing more than the electrical discharge moving through bad conducting matter, under an explosive form, the tendency of a lightning rod is to deprive the discharge of this form from the instant it falls on the point of the rod, and by converting it into an evanescent current, through matter calculated to assist its progress, to annihilate it as lightning altogether.

In the treatment of this question, it was not possible to avoid a frequent appeal to electrical action, on the great scale of nature. If, therefore, the remarkable instances quoted, of lightning striking on buildings and ships, should appear to be somewhat numerous, and to be treated of in too great detail, yet it must be recollected, that it is only by pursuing such a course that we can hope to arrive at deductions worthy of confidence. Hence it is, that in the progress of these inquiries we have been led to adhere carefully to a series of well-authenticated facts, and by keeping strictly within the safe path of inductive science, we have endeavoured to throw some further light on a subject of very great public importance, which has not been generally or fully appreciated. With respect to certain prejudiced views and opinions which have been entertained of the operation of lightning rods, we trust to have made it appear, that such opinions are founded on no sound basis whatever; and that a judicious application of pointed conductors, both on land and at sea, is not only desirable, but is, in a great variety of cases, quite essential to the preservation of buildings and ships from the ravages of lightning.

THE END

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